Volume 14 DECEMBER 1930 Number 12

BULLETIN
of the
American Association *of* Petroleum Geologists

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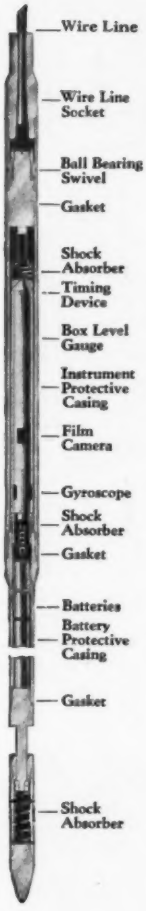

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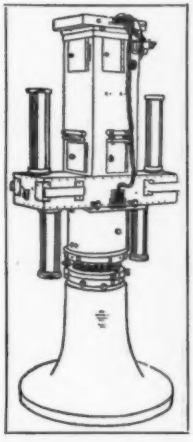

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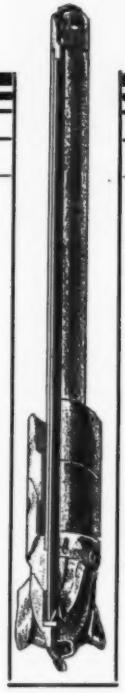

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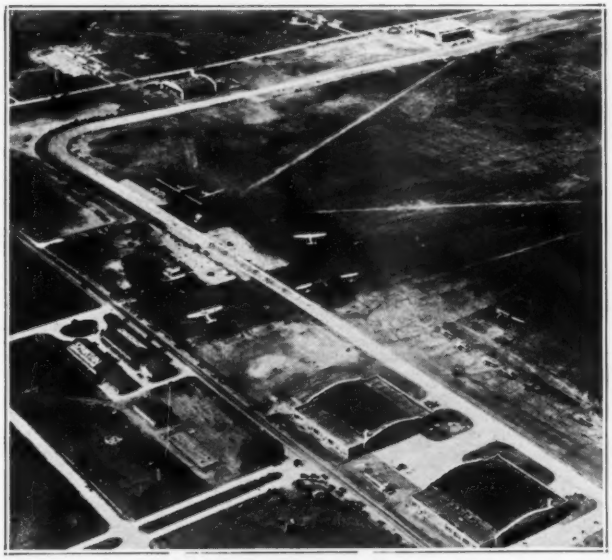

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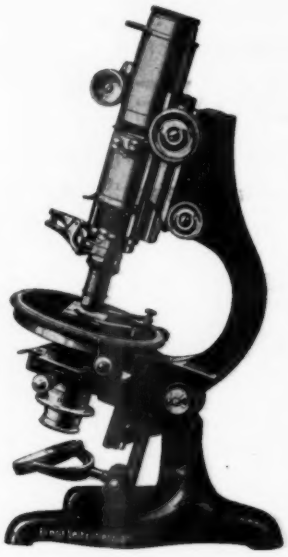

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Volume 14 Number 12

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

DECEMBER 1930

SIMPSON GROUP OF ARBUCKLE AND WICHITA MOUNTAINS, OKLAHOMA[1]

CHARLES E. DECKER[2]
Norman, Oklahoma

ABSTRACT

A brief review is given of the steps taken in the study of the Simpson which resulted in recognizing it as a group of formations rather than a single formation. Reasons are cited for reducing the number of the formations from the seven temporarily postulated, to five. Eight short tables are included to show the changes in classification, and three tables of columnar sections along one east-west and two north-south sections show the marked variations in the composition and thickness of the Simpson in its outcrops.

As the sandstones in the Simpson are considered among the most important oil horizons in the state and also are important as sources for asphalt and glass sand, it has seemed desirable to study the outcrops of the Simpson in considerable detail. The need for this study is emphasized by great differences in the formations in this group and by the fact that there are more than twenty separate outcrops.

It is proposed here to review briefly the history of the correlation of the Simpson, show the relation of its parts by graphic tables, show one east-west and two north-south sections, giving thickness of formations and their correlation, and give an idea of the present status of the investigation.

[1]Read before the Association at the New Orleans meeting, March 22, 1930. Manuscript received by the editor, July 7, 1930. Published by permission of the director of the Oklahoma Geological Survey.

[2]Professor of paleontology, University of Oklahoma.

J. A. Taff, with the able assistance of E. O. Ulrich, did an excellent piece of geological work in his study and differentiation of the Paleozoic formations of the Arbuckle Mountains and the Wichita Mountains of Oklahoma.

Taff, in his first publication of the United States Geological Survey in the Tishomingo Folio, in 1903, divides the Simpson into a lower and an upper part as shown in Table I. The lower part is correlated with Chazy and the upper part with upper Stones River and with a tentative suggestion of Black River.

The next year, in 1904, in United States Geological Survey Professional Paper 31, the same division into parts is used and is shown here in Table II. Also the correlation is nearly the same, the only difference being that Black River is omitted from the upper part.

In a tentative correlation table published by the United States Geological Survey in June, 1925, the Simpson as a whole is made equivalent to Lower Ordovician, as shown in Table III.

In Table IV, a part of a correlation table is shown. This was made by Ulrich in the spring of 1928. In it the Simpson is divided into three formations, Oil Creek, Bromide, and West Spring Creek, the last having a Criner member. Here the Oil Creek and Bromide are correlated with the Chazy, and the West Spring Creek with Trenton and Black River. It is to be particularly noticed here that the upper part of the Simpson is definitely recognized as Trenton and Black River in age, and the writer believes that sufficient evidence has accumulated now to justify that correlation, though there is a question about the desirability of the names here used for that upper part. It should be noticed also that Bromide is placed considerably below the top and correlated with upper Chazy.

Table V was presented by Ulrich at the meeting of the Geological Society of America in New York late in 1928. This seven-part division of the Simpson was developed after the writer had given somewhat extended study to various outcrops of the Simpson and after Ulrich had shared with him the field problems in a short trip in the spring of 1928. It was developed also after they had an opportunity to study together in the U. S. National Museum for a brief period the faunas of various parts of the Simpson.

The purpose was to divide the Simpson into formations which would represent the natural physical and faunal subdivisions. In the western and southwestern parts of the region a breccia or conglomerate occurs at the base of the Simpson and four major sandstones occur within it. Accordingly, five formation names were given to the five divisions, each

TABLES I, II, AND III

I

TISHOMINGO FOLIO Page 3
J.A. TAFF 1903

SIMPSON	UPPER	Black River ? Upper Stones River
	LOWER — Chazy	

II

U.S.G.S. PROF. PAPER 31
J.A. TAFF 1904

SIMPSON	UPPER — Upper Stones Riv.	
	LOWER — Chazy	

III

TENTATIVE CORRELATION TABLE
U.S.G.S. JUNE, 1925
(IN PART)

SIMPSON — Lower Ordovician

TABLE IV

TENTATIVE CORRELATION TABLE (IN PART)
AFTER ULRICH, U.S.G.S.
APRIL, 1928

	GENERALIZED		ARBUCKLE
ORDOVICIAN	Cincinnatian	Maysville gr.	
		Eden gr.	Viola ls.
	Mohawkian	Trenton gr.	
		Black Riv. gr.	West Spring Cr. Criner member
	Chazyan (Tenn.)	Blount gr.	Bromide fm.
		Lenoir ls.	Oil Creek fm.
		Mosheim ls.	
	Buffalo River series (Arkansas)	Joachin ls.	
		St. Peter ss.	
		Everton ls.	
		Kings Riv. ss.	
		Sneed ls.	

TABLE V

TABLE BY E.O. ULRICH
G.S.A. NEW YORK 1928
Reported by Dr. Chas. N. Gould

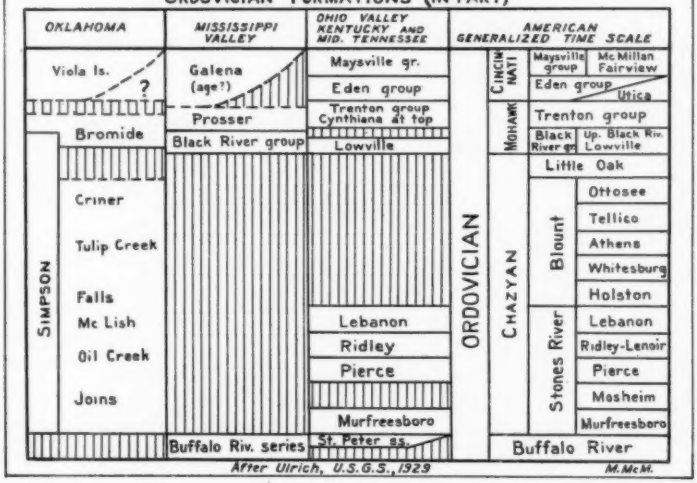
ORDOVICIAN	Viola
	Bromide
	Criner
	Tulip Creek
	Mc Lish
	Falls
	Nebo
	Joins Ranch

representing a more or less complete sedimentary cycle. The five names first used for the five formations in the western part are: Joins Ranch, Nebo, Falls, Tulip Creek, and Criner. In a similar manner in the eastern and central parts of the region three major sandstones are separated by limestones. To these three divisions the formation names Nebo, McLish, and Bromide were given, the last two being different from any of those in the western part of the region. It was thought then that these two formations differed distinctly faunally from those on the west. A noteworthy change is the transfer of the Bromide from a central position to the top of the list of formations where it was recognized as belonging because of the position of the type section at Bromide. McLish was given as the name for a formation which has a limited but very distinctive fauna which was thought then to be confined wholly to the eastern part of the region.

Table VI is a small part of a large section made by Ulrich after extensive study of the Ordovician of England last fall (1929). In that part in which the Simpson is shown, the Bromide is placed at the top and correlated with Prosser (or Trenton) and Black River. Also, the Bromide is separated considerably from the six older formations below

TABLE VI

SUGGESTED CORRELATIONS OF AMERICAN AND EUROPEAN ORDOVICIAN FORMATIONS (IN PART)



it. This suggests that the fauna of the Bromide is much younger than that of the other formations. However, more extended collections, both north and south of the type Bromide section, have supplied much evidence to show that the Bromide of the eastern part of the region at Bromide and vicinity is very much like the upper part of the Simpson in the southwestern part of the region and at the south end of the Criner Hills. The other six formations are placed opposite the Chazy as though all were assigned to it. If the Criner is considered to represent the upper part of the Simpson as exposed at the type locality at the south end of the Criner Hills, or as developed at West Spring Creek, it is thought that the former classification was more nearly correct, as it carries a dominantly Black River fauna with a few forms that range up into the Trenton.

McLish is placed beneath the Falls formation, whereas in the former table it was placed above the Falls. The last word from Ulrich in regard to this was to the effect that the position of the McLish is a problem, but he thought it should be placed below rather than above the Falls. Oil Creek was substituted for Nebo, as the latter name was previously assigned to a Cambrian formation of Tennessee.

Table VII shows the Simpson formations given in an advance correlation table sent out by the Oklahoma Geological Survey to geologists in February of this year (1930). Here the number of formations is reduced from seven to five, with the correlation of the upper two with Black River and the lower three with Chazy. The reduction to five formations was made after new collections were secured both north and south of the type section at Bromide, and these new collections supplied forms which show that the major part of the fauna at the top of the Simpson at Bromide is similar to most of the forms found in the upper part of the Simpson in the western and southern part of the Arbuckle Mountains and in the Criner Hills. As Bromide has been used more extensively in connection with the Simpson, it seems best to retain it for the upper formation and drop Criner.

The fauna from the Tulip Creek was extremely meager, and Ulrich expressed the opinion that it is older than Black River. However, this decision was reached before new collections of pelecypods, bryozoans, and cephalopods were secured and sent to him.

Falls was dropped because it was thought that some evidence had been secured to make the body of rocks representing the McLish equivalent to a part or nearly all of the Falls. Though the major elements of the fauna typical of the McLish have not been traced west of Roff and

TABLE VII

ADVANCE TABLE OF SIMPSON FORMATIONS
C. E. DECKER AND C. A. MERRITT
FEB. 1930

GENERAL EASTERN SECTION	OKLAHOMA
Black River	Bromide
	Tulip Creek
Chazy	Mc Lish
	Oil Creek
	Joins
Beekmantown?	Conglomerate

TABLE VIII

SUGGESTED CORRELATION OF SIMPSON
C. E. DECKER MAR. 19, 1930

GENERAL EASTERN SECTION	OKLAHOMA
Trenton and Black River	Bromide
? ?	Tulip Creek
Chazy	Falls / Mc Lish
	Oil Creek
	Joins
Beekmantown?	Conglomerate

M. McM.

Sulphur, the cystid zone which occurs in the middle of what has been called Falls in the Ardmore-Davis Highway 77 does extend eastward, and occurs in the middle of the McLish near Sulphur, Roff, and Connerville. Furthermore, the Birdseye-like limestone which is so characteristic of the McLish of the eastern and central part of the region is typically developed to the extent of 85 feet at the north end of the Criner Hills. At this latter locality this special type of limestone lies between a cystid zone above and a bryozoan zone below, which are thought to represent respectively the cystid zone in the middle of the Falls, and the bryozoan zone a short distance below the top of the Oil Creek on the Ardmore-Davis Highway 77.

Beekmantown appears with a question mark and probably it should not be used at all. It was placed there because of a graptolite *Didymograptus artus* which occurs a short distance above the base of the Joins formation and its distribution is practically co-extensive with the outcrop of that formation. Ruedemann has stated that this graptolite is a common associate of *Didymograptus bifidus* which is shown in a table[1] as

[1]Rudolph Ruedemann, "Graptolites of New York," *New York State Mus. Memoir II*, Part 2 (1908), table opp. p. 10.

occurring at the top of the Beekmantown. *D. bifidus* is of interest because of its wide geographic range, being found in New York, Canada, Scandinavia, France, Bohemia, and Australia. However, it is not certain yet that *D. artus* may not range higher in this region, where it seems to be associated with some lower Chazy forms.

Table VIII represents only a slight modification of Table VII. In the latter table Bromide is correlated with Trenton and Black River; Tulip Creek is left with horizon undetermined until its fauna can be studied more fully. Falls is still retained for the western part of the area until it can be determined more definitely whether or not it represents a western extension of the McLish.[1]

Table IX shows four measured sections of the Simpson, beginning with one at West Spring Creek at the west end of the Arbuckle Mountains, a second north of Springer on the Ardmore-Davis Highway 77, a third on Sycamore Creek west of Ravia, and a fourth on the Robertson Ranch south of Bromide at the east end of the mountains.

The greatest thickness of the Simpson is on the south and west sides of the Arbuckle Mountains along the Ardmore-Davis Highway 77, and on Sycamore Creek, where it exceeds 2,200 feet. On the south side of the mountains the thickness decreases eastward to slightly more than 1,600 feet on the Robertson Ranch. In this east-west section, more shales occur in the upper part of the Simpson at the west end and more limestones toward the east. In the lower part of the Simpson more limestones occur in the western and south-central parts and more sandstones in the southeastern part. The sandstone at the base of the Oil Creek formation in the West Spring Creek area is only about 8 feet thick. It thickens eastward to 20 feet at the Ardmore-Davis Highway 77, and to 200 feet at Sycamore Creek. It should be noticed that two of the formations, Joins and Tulip Creek, are local in their distribution, occurring only in the west, southwest, and central parts of the Arbuckle Mountains.

In Table X five measured sections of the Simpson are shown, beginning with one at the south end of the Criner Hills, one at the north end, the Ardmore-Davis Highway 77 section, one at the south side of Falls Creek, and one west of Davis on the C. R. Russell ranch. In the short section at the south end of the Criner Hills there is a slight erosional unconformity between the Viola and the top of the Simpson,

[1]Since the New Orleans meeting of this Association, the McLish fauna has been found in a section 8 miles southeast of Sulphur in the midst of limestone above the Tyner cystid zone, thus clearly making the McLish of the east equivalent to what was called Falls at the west. Therefore, the latter name is dropped.

TABLE IX

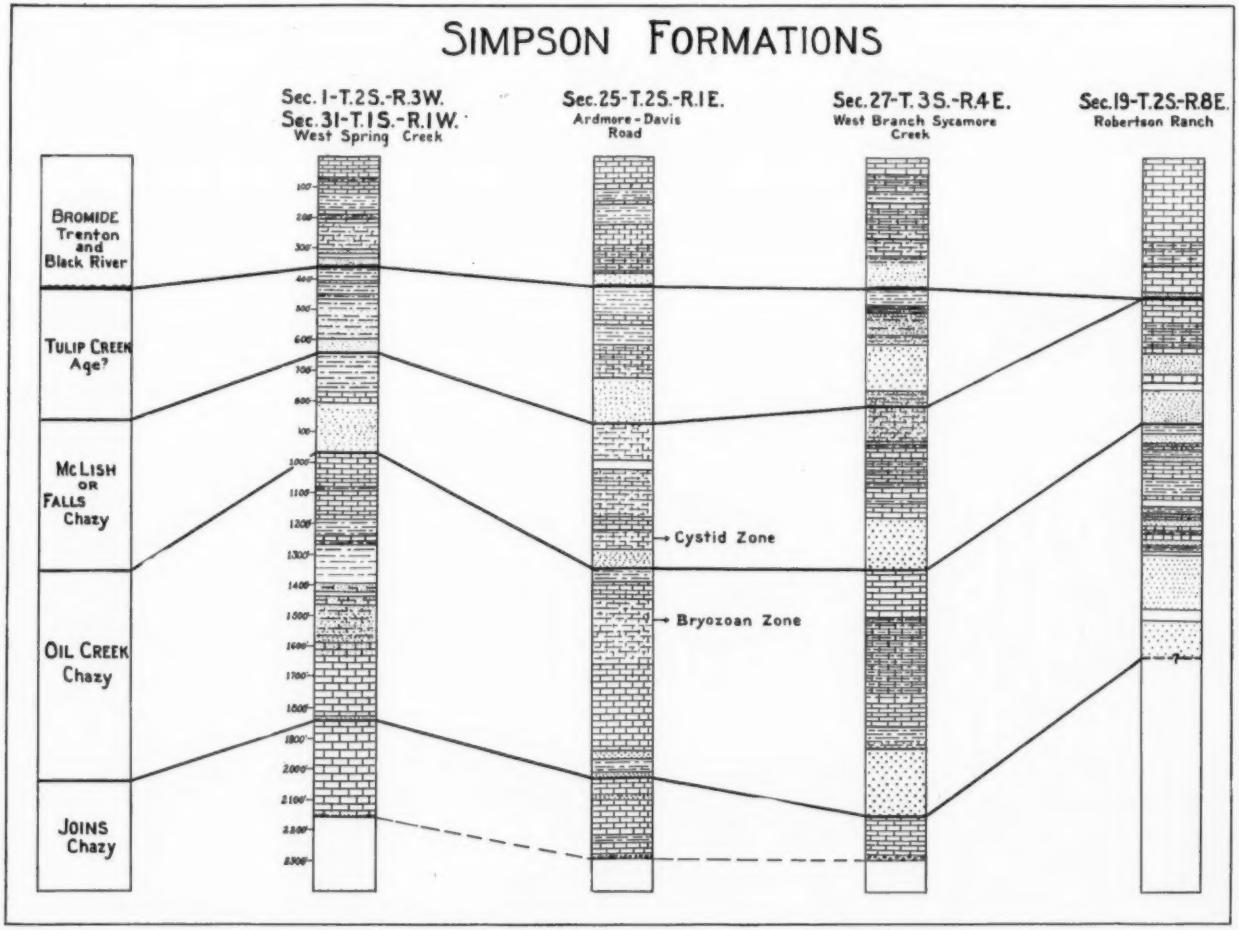
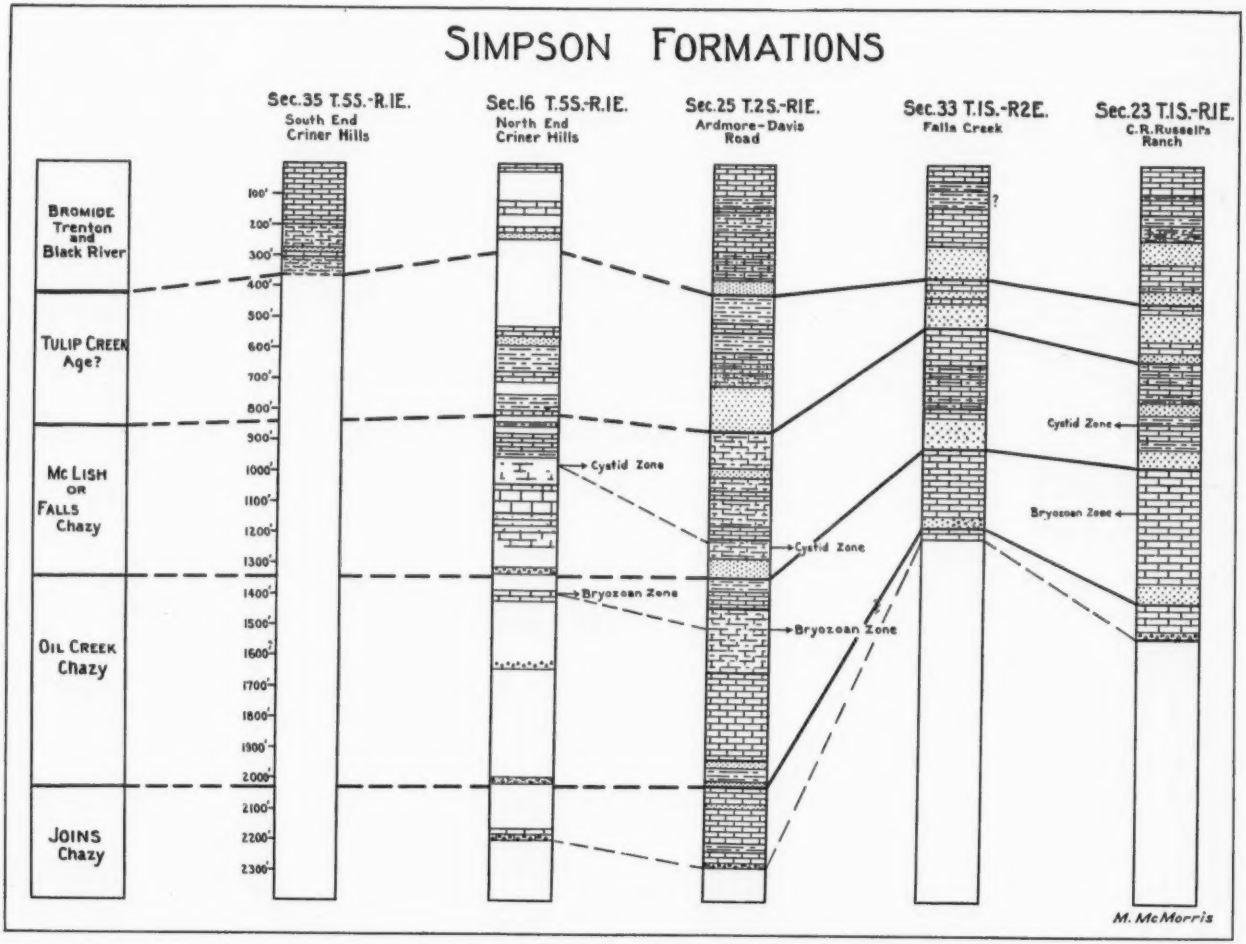


TABLE X

TABLE X


SIMPSON FORMATIONS
Sec.35 T.5S.-R.1E.
South End
Criner Hills
Sec.16 T.5S.-R.1E.
North End
Criner Hills
Sec.25 T.2S.-R1E.
Ardmore-Davis
Road
Sec.33 T.1S.-R2E.
Falls Creek
Sec.23 T.1S.-R1E.
C.R.Russell's
Ranch
BROMIDE
Trenton
and
Black River
TULIP CREEK
Age?
Mc LISH
OR
FALLS
Chazy
OIL CREEK
Chazy
JOINS
Chazy
100'
200'
300'
400'
500'
600'
700'
800'
900'
1000'
1100'
1200'
1300'
1400'
1500'
1600'
1700'
1800'
1900'
2000'
2100'
2200'
2300'
Cystid Zone
Bryozoan Zone
Cystid Zone
Bryozoan Zone
Cystid Zone
Bryozoan Zone
M. McMorris

and the basal part of the Bromide formation is covered with Pennsylvanian conglomerate. Though a slightly abbreviated section of the Bromide, it contains all of the major elements of the fauna and the marked faunal zones characteristic of the upper part of the Simpson in the Arbuckle Mountains on the north, including the two sponge zones, and the marked brachiopod, bryozoan, cystid, cephalopod, and trilobite zones.

At the north end of the Criner Hills there is a complete section of the Simpson, including the sponge zone at the top and the breccia at the base next to the Arbuckle limestone. This section of the Simpson is of less value than many others, because much of it is thickly covered with soil. However, in the central part of the section there is a remarkably fine outcrop of the Birdseye-like limestone which is characteristic of the McLish formation in the eastern part of the region. It seems strange that this limestone, which is characteristic of the McLish on the east, has such a marked development here and does not occur at all in the western end of the Arbuckle Mountains, only about 20 miles farther north. But it does lie between the cystid zone, which is well developed in what has been called the Falls on the Ardmore-Davis Highway 77, and the bryozoan zone near the top of the Oil Creek formation, giving a suggestion here of at least partial equivalence of the McLish and Falls, and this idea is strengthened by the fact that this cystid zone extends eastward to Sulphur, Roff, and Connerville, in the middle part of the McLish.

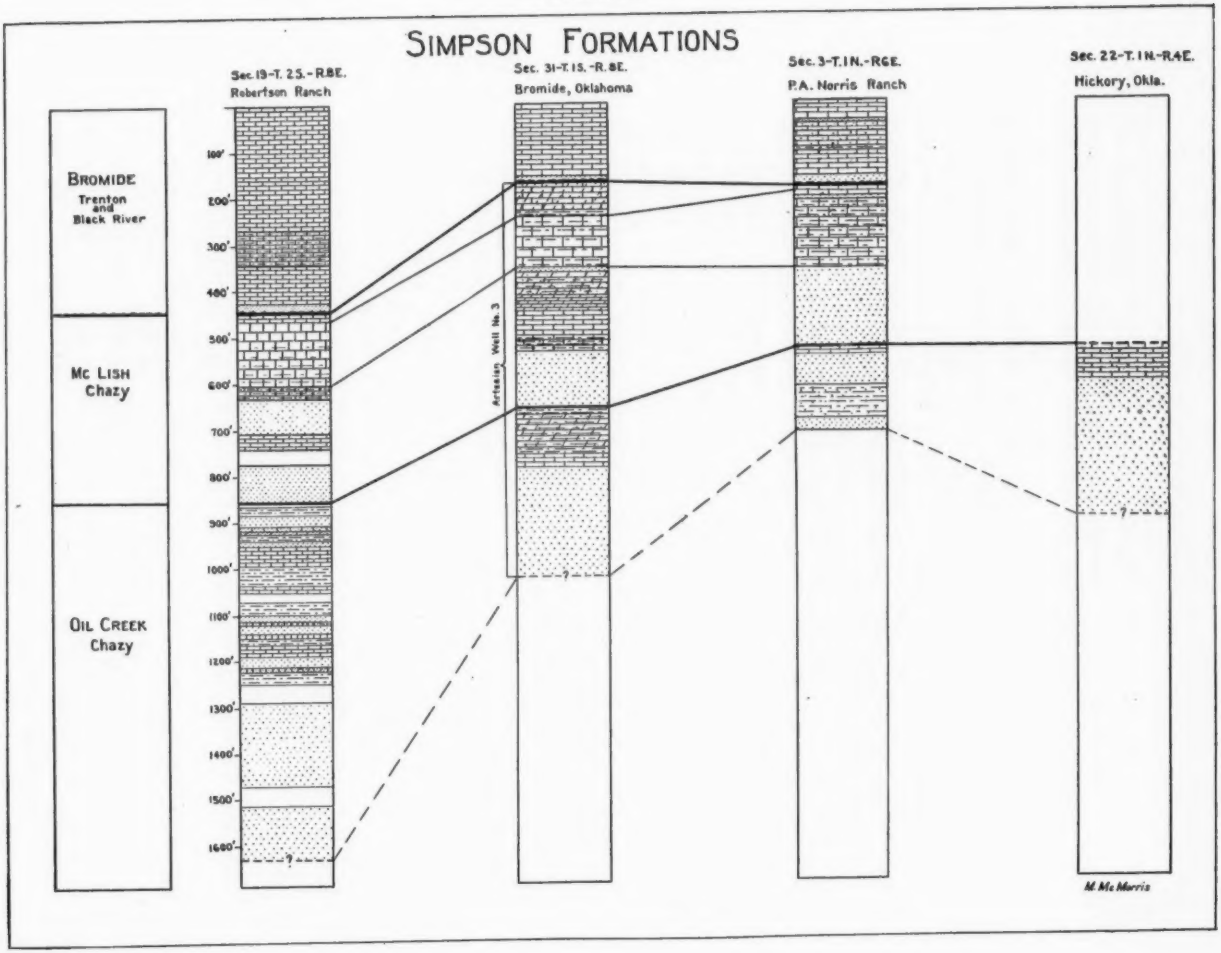
The Falls Creek section is particularly abbreviated, being only slightly more than 1,200 feet in thickness, only a small amount more than half that of the section measured a few miles farther south. Though all five of the formations are present, the thickness of all is decreased somewhat, but especially that of the Tulip Creek, the Oil Creek, and the Joins, the last being only 30 feet thick.

The section north of this on the C. R. Russell ranch is not so short, but it has about 700 feet less of sediments than the sections on the south side of the mountains. This shows a very marked thinning of the Simpson northward in a distance of not more than 10 miles. All the formations are present. The section may not be as accurate as the others. The topography is rough and it was measured by pacing.

Table XI shows sections at the east end of the Arbuckle Mountains and one north of the center, at Hickory. Only three formations have been differentiated in the Simpson in this eastern region, the Oil Creek, McLish, and Bromide.

TABLE XI

TABLE XI


SIMPSON FORMATIONS
Sec. 19-T. 2S.-R.8E.
Robertson Ranch
Sec. 31-T. 1S.-R. 8E.
Bromide, Oklahoma
Sec. 3-T. 1N.-R6E.
P.A. Norris Ranch
Sec. 22-T. 1N.-R4E.
Hickory, Okla.
BROMIDE
Trenton
and
Black River
Mc LISH
Chazy
OIL CREEK
Chazy
100'
200'
300'
400'
500'
600'
700'
800'
900'
1000'
1100'
1200'
1300'
1400'
1500'
1600'
?
Artesian Well No. 3
?
?
M. Mc Morris

The *Rafinesquina minnesotensis* zone, so well developed at the top of the Bromide farther west, and the bryozoan-cystid zone, which occurs above the basal sandstone of the Bromide, are both well developed in this eastern region.

In the section farthest south, on the Robertson Ranch about 4 miles south of Bromide, all three formations are well developed. It is difficult to measure correctly the thickness of the Oil Creek formation because a low anticline several hundred feet wide occurs in the midst of it. The total thickness is about 1,600 feet, or nearly 700 feet less than in the southwestern part of the mountains. Toward the base of the Oil Creek formation the sandstones grade into sandy soils which extend over a flat field, and these grade into the soils from the weathered granite on the south, so that the Arbuckle is absent where the section was measured and it is impossible to determine accurately the location of the base of the Simpson. The McLish formation is well represented, with some dolomitic beds at the top and about 70 feet of the Birdseye-like limestone below. Next below are the shaly limestones, with the typical McLish zone of sponges, corals, brachiopods, and gastropods; and next below, with some included limestones, the unindurated sandstone which is typical of the bottom member of the McLish in the entire eastern part of the region and at the sand pit at Roff. In the Bromide a relatively large amount of limestone occurs with a relatively less amount of shale than is generally present farther west.

In the section at the north edge of Bromide, the Bromide formation is exposed above Artesian well No. 3 and the remainder of the section represents the log of the well. The Oil Creek formation consists of dolomites and limestones at the top, with about 200 feet of soft sand below. Drilling was stopped by a cave-in with the bit still in the sands. The basal sand in the McLish is 125 feet thick, with limestones and dolomites above. The Bromide has a thickness of 171 feet, consisting chiefly of limestones, with a minor amount of shales, and a thin sandstone at the base. The total thickness is about 1,000 feet, or about 600 feet less than in the section about 4 miles farther south.

Northwest of this last section about 25 miles, or 2 miles southwest of Franks, the section was made on the P. A. Norris Ranch. All three formations are represented in this section, but the total thickness is reduced to slightly more than 700 feet. This thickness was figured from paced measurements. Also this is a composite section, with the basal part measured about ¼ mile north of the point where the top was measured.

Considerable shale occurs in the sandstones near the base of the Oil Creek and only about 12 feet of limestone at the top. This limestone commonly is coarse, yellowish brown, and contains breccia or coarse conglomerate, probably giving evidence of extended erosion which may be chiefly the cause for the thinness of the limestones in the Oil Creek.

The McLish has 170 feet of soft sand at the base and there is about 170 feet of limestone, much of it Birdseye-like, with some dolomites below and above it.

The Bromide has about the same thickness as in the last section near its type area, but there it contains relatively more shale and sandstone.

About 12 miles southwest of this last section, the Simpson at Hickory is represented only by the Oil Creek formation, with 15-30 feet of limestone above and a large amount of soft sand below, the exact thickness of which it is impossible to determine. Thus there is seen to be a general thinning of the Simpson eastward and northward, particularly toward the northeast. Dolomites of any importance in the Simpson are known only in the eastern and northeastern parts of the region. The Simpson and Viola are now being carefully mapped and additional data in regard to thickness will be secured in connection with this work, as well as some additional faunal material from specific horizons. Most of this work of mapping is being done by a party of three, Everett Orr, Wayne Beardsley, and Rex McGehee in charge. Mr. McGehee has proved himself to be a competent field assistant; he has also helped in the identification of parts of various faunas.

R. W. Harris is working on the microscopic forms of the Simpson and has been rewarded by finding more than 35 species in the Bromide formation alone.

SIMPSON OF CENTRAL OKLAHOMA[1]

T. E. WEIRICH[2]
Tulsa, Oklahoma

ABSTRACT

Lateral gradation of lithology and southward divergence of strata are distinguishing characteristics of the Simpson formation. Lithologically, the exposed section in the Arbuckle Mountains can not be correlated with the subsurface section southwestward into Stephens County or northeastward into the Seminole district. The section at Oklahoma City can be satisfactorily correlated with that in Creek County with the addition of a "lower Simpson" (pre-Burgen) section not present in Creek County.

Complete erosion in northeastern and southwestern Oklahoma prevents determination of the thickness of the Simpson in these localities. Measurements at the outcrop in the Arbuckle Mountains and from wells drilled in central Oklahoma show that the formation diverges from a thickness of about 200 feet in the vicinity of Arkansas River to 2,400 feet on the southeast rim of the Arbuckle Mountains.

INTRODUCTION

The Simpson formation, of Ordovician age, is especially important to Oklahoma geologists because several sand members, including the "Wilcox" sand, yield large quantities of oil in the state. Hence, intensive study of the Simpson has resulted in many excellent papers. White[3] subdivided the formation in northern Oklahoma into five members: post-"Wilcox," "Wilcox" sand, Tyner shale, Burgen sandstone, and lower Simpson beds.

For well-to-well correlation purposes, these subdivisions may be used throughout the oil-producing region of northern and central Oklahoma.

The location of the type section of the Simpson formation is in the Arbuckle Mountains of southern Oklahoma, where the formation was originally studied and named. Because of lateral gradation, however, the Arbuckle type section can not be traced by lithology into the subsurface north of the mountains.

[1]Read before the Association at the New Orleans meeting, March 22, 1930. Manuscript received by the editor, October 1, 1930.

[2]Geologist, Tidal Oil Company.

[3]Luther H. White, "Correlation of the 'Wilcox' Sand Series," *Oklahoma Geol. Survey Bull. 40*, Vol. I (July, 1928), pp. 21-40.

GENERAL FEATURES OF SIMPSON FORMATION

The problem of correlation of the Simpson beds in Oklahoma is two-fold: southward divergence in thickness and lateral gradation of lithology.

SOUTHWARD DIVERGENCE

Measured sections of the Simpson in scattered wells throughout central Oklahoma and at its outcrop in the Arbuckle Mountains have furnished a mass of data demonstrating a thickness of approximately 200 feet in Tulsa, Pawnee, and Noble counties, with a gradual thickening southward to a maximum of nearly 2,400 feet on the southeast rim of the Arbuckle Mountains (Fig. 1). The formation is absent entirely, because of truncation, in northeastern Oklahoma, in part of the Arbuckle Mountains, in southwestern Oklahoma including the Wichita Mountains, and at the apices of certain subsurface folds, notably in the Cushing, Dilworth, Garber, and Oklahoma City oil fields.

Very little information of total thickness south of the Anadarko and Ardmore basins is available. Some wells which have penetrated the pre-Pennsylvanian section in Stephens County have encountered the Viola limestone and the underlying Simpson beds without having reached the Arbuckle limestone.[1] Close proximity of these wells to others that have proved Pennsylvanian rocks to be resting directly upon the Arbuckle, is an indication that the Simpson probably does not exceed 1,500 feet in thickness in central Stephens County. This indication suggests a thinning of the Simpson southward from the Anadarko Basin. Yet the measurement of 2,120 feet in the Criner Hills by Decker and Merrit[2] does not indicate a noticeable thinning of the formation as compared with the thickness at the outcrop in the Arbuckle Mountains (1,831-2,391) feet on the north. The total thickness of the Simpson in the Healdton field can not be determined because of its unknown rate of dip and lack of knowledge about the Simpson-Arbuckle limestone contact. Thus the present evidence is scarcely sufficient to determine whether the Simpson formation continues to diverge southward across the entire state or whether the greatest thickness is in the Ardmore and Anadarko basins with northward divergence in Carter and Stephens counties.

[1]Frank Gouin, "The Geology of the Oil and Gas Fields of Stephens County, Oklahoma," *Oklahoma Geol. Survey Bull. 40-E* (October, 1926), p. 12.

[2]C. E. Decker, and C. A. Merritt, "Correlation Table of Formations of the Simpson Group," *Oklahoma Geol. Survey Advance Mimeographed Notice* (January 21, 1930).

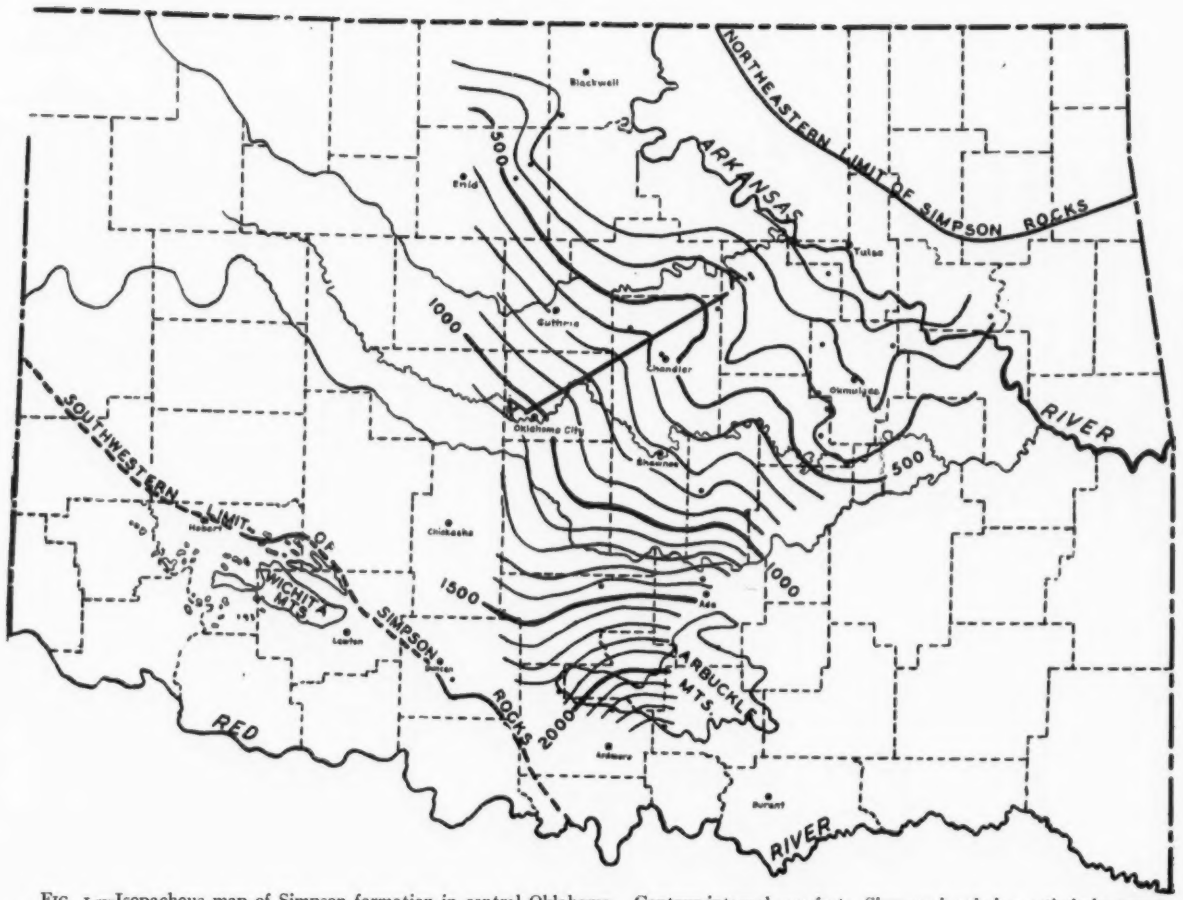


FIG. 1.—Isopachous map of Simpson formation in central Oklahoma. Contour interval, 100 feet. Simpson is missing entirely by truncation in northeastern and southwestern Oklahoma, as indicated on map.

LATERAL GRADATION

In general, the Simpson formation is composed mainly of sandstone in northern Pontotoc and Garvin counties, of sandstone and shale on the immediate north flank of the Arbuckle Mountains and in central and northern Oklahoma, of limestone and sandstone on the south limb of the Arbuckle Mountains, and of shale in Stephens and western Carter counties. Individual members can not be traced with certainty very far by lithology alone. Division by faunal evidence into Black River and Chazy encounters difficulties because of paleontological controversy.

DESCRIPTION OF SIMPSON SUBDIVISIONS

White's[1] subdivisions are used in this paper because of general usage and practicability in central Oklahoma.

No attempt is made here to describe in minute detail the lithology of the post-"Wilcox" member. Subdivisions of this member generally used by Oklahoma geologists and originating in the Seminole district[2] are: "Lithographic (or Dense) lime," "First dolomite," "Seminole sand," and "Second dolomite."

Lateral gradation of these sediments is not applicable except for the "Seminole sand." In the Lovell pool of Logan County the "Seminole sand" is composed of green shales and sands; in the Seminole district, of sand; and in the Maud and Ada districts, of dolomite.

The post-"Wilcox" member as a whole diverges southwestward across the state. The thickness is 25-50 feet in Creek and Okmulgee counties, 200 feet in the Seminole district, and reaches a maximum of 620 feet on the south flank of the Arbuckle Mountains.

The "Wilcox" sand member retains its distinction as a pure sand interstratified with minor thin layers of green shale throughout the central part of Oklahoma. Its position in the Arbuckle Mountains section is questionable. Here the "Wilcox" may have merged into limestone. Total thickness of a sandstone immediately below the post-"Wilcox" near Ada is 625 feet, and near Pauls Valley the maximum thickness of 900 feet is found. Opinion of Oklahoma geologists is diverse regarding the proper position of this great sand thickness. Many are inclined to believe that this sand represents the "Wilcox" sand in its entirety, younger and upper beds having entered the section from the

[1]Luther H. White, *op. cit.*

[2]A. I. Levorsen, "Greater Seminole District, Seminole and Pottawatomie Counties, Oklahoma," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 333.

south, or that it merely represents southward divergence in thickness. Others believe the "Wilcox" is represented only in the upper 200 feet of the sandstone, the lower part being underlying members that have changed character. Because other districts[1] exhibit a section entirely of sandstone from the upper surface of the "Wilcox" sand to that of the Arbuckle limestone, and because well logs only a few miles south of Ada prove the lower part of the great sandstone thickness to have graded into shales, the evidence favors the latter conclusion.

Lateral gradation of lithology in the Tyner member is a prevailing characteristic. In general the member is composed of green or dark shale with included sand or maroon shale zones. The upper surface may consist of shale, sandstone, or sandy dolomite. Ordinarily the middle part is characterized by maroon shales. In consideration of the heterogeneity of the Tyner, it is fortunate that these maroon shales are present, because they afford definite means of correlation. Cram[2] tentatively places the contact between Black River and Chazy in this zone of maroon shales. The lower Tyner consists of sandstone, dolomite, or shale. The member may be correlated with some degree of certainty throughout northern and central Oklahoma as far south as Seminole and Wewoka. Absence of the maroon shales in wells drilled in Pontotoc and Garvin precludes the tracing of the Tyner into these districts.

The Burgen member, like the "Wilcox," is a pure sandstone. Shales and dolomites, although present, are relatively insignificant. The writer is inclined to believe the "School land" sand of the Oklahoma City oil field is the equivalent of the Burgen sand.

White[3] designated that part of the Simpson below the Burgen sand as the "lower Simpson beds." Not being present in the Creek and Okmulgee region, this "lower Simpson" has received little notice. Because of its productivity of oil and gas in the Oklahoma City field, the member is now being intensively studied. The "lower Simpson" is not present on the apex of the Cushing anticline in Creek County, but enters the section on the immediate west limb, whence the zone may be correlated westward to wells drilled in or near the Oklahoma City field (Fig. 2).

[1]Samples from many wells drilled in Noble and Kay Counties wherein the entire normal Simpson section is present prove the latter to consist almost entirely of sandstone. Samples from a well drilled in Section 13, T. 12 N., R. 11 E., Okfuskee County, proved the entire Simpson section to be sandstone except for thin layers of maroon shale which are a part of the "Tyner" shale.

[2]Ira H. Cram, "Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull. 40, Oil and Gas in Oklahoma*, Vol. III (1930), pp. 545-46.

[3]Luther H. White, *op. cit.*

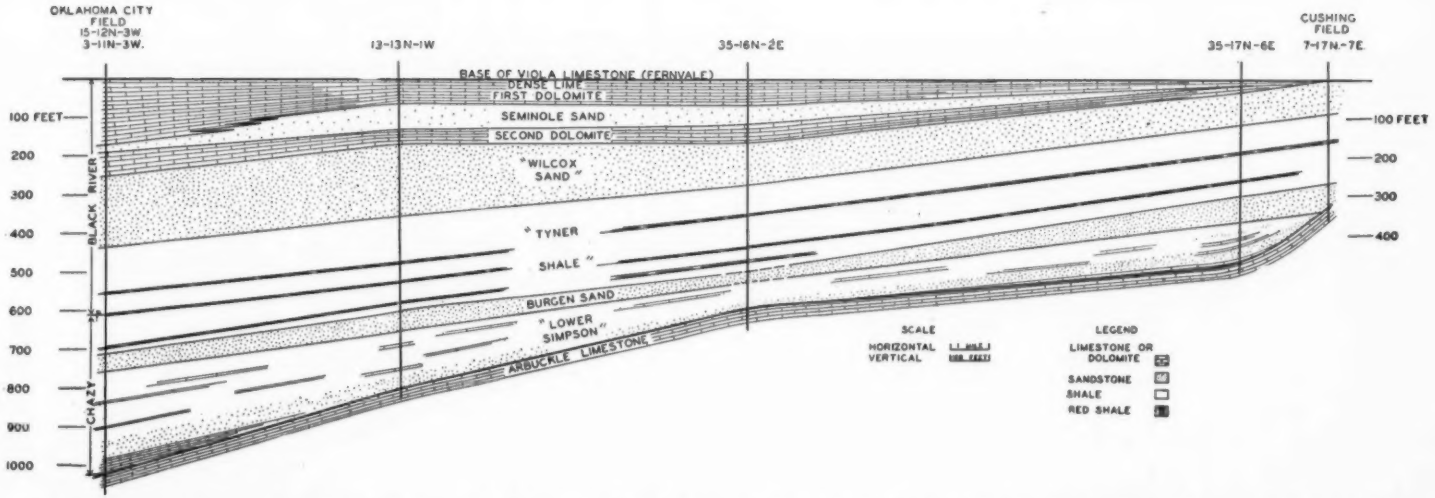


FIG. 2.—Southwest-northeast section (*A-A'*, Fig. 1) of Simpson beds from Oklahoma City field to Cushing field, showing southwest divergence of strata. "Lower Simpson" not present in Cushing field. Section at Oklahoma City constructed from known sequence of beds as revealed by several well logs. Tentative division into Black River and Chazy ages as indicated is after Ira Cram.

The member consists of sands, shales, and dolomites that may not be correlated very far. With knowledge obtained from wells drilled southwest of Creek and Okfuskee counties, individual beds of the "lower Simpson" may be traced without question in the near future.

OKLAHOMA CITY OIL FIELD, OKLAHOMA[1]

HOMER H. CHARLES[2]
Bartlesville, Oklahoma

ABSTRACT

The Oklahoma City oil field, just outside the southeastern limits of Oklahoma City, Oklahoma, was discovered on December 4, 1928, by the Indian Territory Illuminating Oil Company and Foster Petroleum Corporation with their Oklahoma City No. 1, center SE. ¼, SE. ¼, Sec. 24, T. 11 N., R. 3 W., at a total depth of 6,402 feet. The field is on a faulted anticline in which formations ranging from Mayes limestone of Mississippian age to Arbuckle limestone of Cambro-Ordovician age have been folded, truncated, faulted by one major fault, and then buried under Cherokee shale and succeeding beds of Pennsylvanian and Permian age. The oil (38°-40° Bé. gravity) occurs in thin rich pay zones ranging from 200 to 500 feet below the top of the Arbuckle limestone, which is directly beneath the Cherokee shale at the highest part of the structure, and in sandstones of the Simpson formation which flank the Arbuckle. Shallower sands in the Pennsylvanian having showings of oil and gas have not yet been tested. The initial oil production of the wells ranges from 1,000 to 43,000 barrels and the maximum gas volume is 150,000,000 cubic feet per day.

By March 10, 1930, there were 135 completed oil wells and 173 drilling wells or locations in the field. The total production at that date was estimated at 14,500,000 barrels. The potential production of the field was 870,000 barrels. Almost from its beginning the field has been radically prorated.

INTRODUCTION

The Oklahoma City oil field lies approximately in the geographic center of the state (Fig. 1). In its present stage of development it occupies an area 5 miles long by 2 miles wide, most of which is in the southeastern part of T. 11 N., R. 3 W. Development has already pushed the northwest side of the field within a mile of the limits of Oklahoma City. Forty miles southeast is the greater Seminole oil district and about the same distance north is the Lovell-Marshall district in Logan County.

The field at present covers about 4,500 acres. This area may be increased to about 11,000 acres when the limits are completely defined.

In this preliminary paper are presented the history of the development of the field and general geological facts which are known at this date (March 10, 1930). A detailed treatise can be given more appropriately

[1]Read before the Association at the New Orleans meeting, March 22, 1930, by R. J. Riggs. Manuscript received by the editor, October 4, 1930. Published by permission of the Indian Territory Illuminating Oil Company.

[2]Geologist, Indian Territory Illuminating Oil Company.

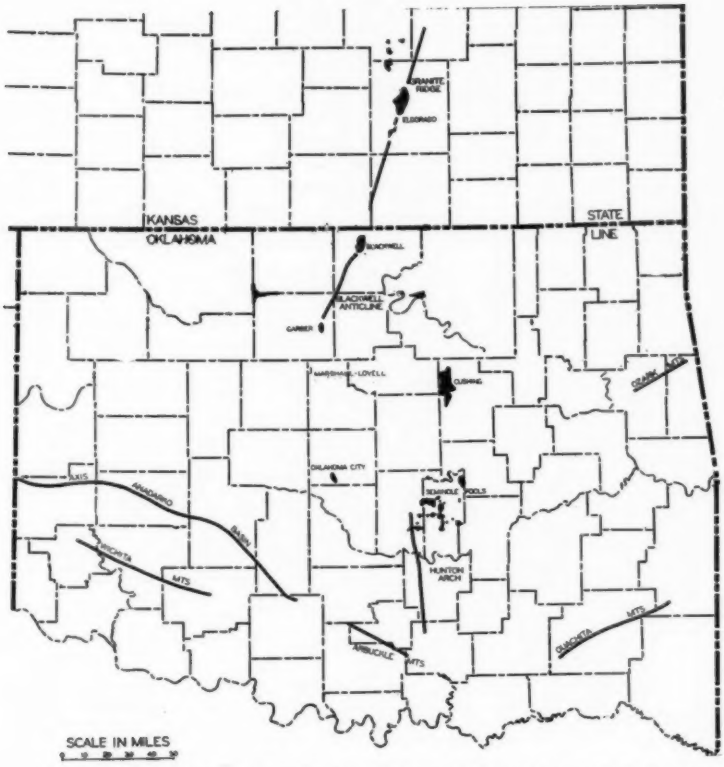


FIG. 1.—Map showing location of Oklahoma City field in relation to chief structural features and oil fields of Kansas and Oklahoma.

when additional data are secured and they are no longer considered confidential.

The subject matter appearing in this paper was presented before the New Orleans convention of the Association by R. J. Riggs.[1]

While the data given here are drawn principally from the files of the Indian Territory Illuminating Oil Company, much information has been secured from geologists of other companies interested in the field who have helped through free exchange in thought. Thanks are due to

[1]Manager of land and geological departments, Indian Territory Illuminating Oil Company.

the management of the Indian Territory Illuminating Oil Company for their permission to publish this paper, and for their encouragement at all times in the effort to secure accurate scientific information.

Developments leading to the completion of the discovery well of the Oklahoma City field began in the summer of 1927 with reconnaissance work by G. E. Anderson, who was in the employ of the Indian Territory Illuminating Oil Company. Sufficient evidence of an uncommonly large anticline southeast of Oklahoma City was gathered by him to cause the company to take all the leases available. The close proximity to a large city made this work difficult because the land was divided into many small tracts, a considerable part being subdivided into 25-foot city lots. This land division has had, and will continue to have, a very serious effect upon the development.

A detailed survey was made by geologists of the company under the direction of J. H. Derden, chief field geologist. The active coöperation of R. J. Riggs and C. W. Roop[1] was given in this mapping and in the geological work attendant upon the development of the leases owned by the company. The extensive duties of sample gathering and subsurface work based on the study of samples and cores were supervised by W. W. Clawson, assisted by L. R. McFarland. Early determination of the formations encountered by the first few wells was made by Robert Roth, micropaleontologist on the company's geological staff.

On account of the great depth that was anticipated for productive formations, the Indian Territory Illuminating Oil Company planned and hoped to inaugurate a system of 40-acre locations. The test well was located in the center of 40 acres, a company lease in fee, the SE.¼, SE.¼, Sec. 24, T. 11 N., R. 3 W., and was named Indian Territory Illuminating Oil Company-Foster Petroleum Corporation Oklahoma City No. 1. The main events in the history of the discovery well are:

Date	*Event*
May 26, 1928	Location staked
June 12	Hole spudded
June 13	Set 15½-inch casing at 125 feet
June 21	Total depth, 2,268 feet. Showing of gas
June 25	Total depth, 2,604 feet. Cored 2,601-2,604 feet. Recovered hard, fine-grained sand, showing gas and oil
July 20	Total depth, 4,012 feet. Cored 3,997-4,012 feet. Sand showing oil. Ran tester. Estimated 25,000,000 cubic feet gas. To drill ahead
July 30	Total depth, 4,233 feet. Cored 4,214-4,231 feet. Sand showing oil and gas

[1]Superintendent of geological division, Indian Territory Illuminating Oil Company.

August 20	Total depth, 4,798 feet. Cemented 9-inch casing at 4,790 feet
September 5	Total depth, 4,816 feet. Layton sand. Gas broke in. Tested 47,721,000 cubic feet. Rock pressure 1,720 pounds per square inch. To kill and deepen
October 24	Total depth, 6,003 feet. Limestone encountered. Identified as Oswego
November 6	Total depth, 6,208 feet. Limestone reported in log. Later identified as Arbuckle. Top from samples placed at 6,148 feet
November 14	Total depth, 6,402 feet. Cemented 7-inch casing at 6,355 feet
November 29	Total depth, 6,402 feet. Making vertical test. Hole shows straight
November 30	Total depth, 6,402 feet. When cement plug was penetrated gas blew in, breaking drilling line and leaving tools in hole. Ran bailer to top of bridge at 2,500 feet. Recovered a bailer of oil. Gas bubbling through
December 4	Total depth, 6,402 feet. Tools blown from hole at 3:00 p. m. Well flowing about 215 barrels oil per hour. Gravity 38° Bé.
December 6	Flowed 4,847 barrels oil

The well was subsequently deepened by stages to 6,624 feet. Its accumulated production on March 10, 1930, was 1,006,721 barrels.

GEOLOGY

TOPOGRAPHY

The Oklahoma City field is in the Permian Red-bed plains area, composed of low rolling hills and wide flat valley floors. The relief is about 165 feet, varying from 1,175 feet above sea-level along the North Fork of Canadian River to 1,340 feet in the southern end of the field. The sandstone outcrops support scrub oaks, but the shale outcrops form rolling barren prairie land.

SURFACE FORMATIONS

The surface formations include the Garber sandstone and Hennessey shale, members of the Enid group of the Permian system.

Hennessey shale.—The Hennessey is made up of reddish brown shale that disintegrates easily under weathering. Lenses of arenaceous sandstone are in the member. The thickness is 600-700 feet in the Oklahoma City area.

Garber sandstone.—This sandstone member, 300 feet thick, underlies the Hennessey shale conformably. It is composed of massive red to orange sandstone lenses and red shale. The heavier sandstone beds are sufficiently resistant to weathering to make the topography rough where

they crop out, but their contact with the interbedded shale is not distinct and the mapping of the surface structure by use of these beds was difficult.

SUBSURFACE FORMATIONS

The Permian red shales, sandstones, and gypsiferous shales extend to a depth of 1,300 feet on top of the structure and the remainder of the Permian beds to about 2,200 feet are brown shales, thin limestones, and lenticular sandstones.

Pennsylvanian formations with a thickness of 3,800-4,000 feet constitute the major part of the subsurface section. They include mostly blue and gray shales, but several limestones and sandstones are present. Among the subsurface members that have been correlated with strata north and east of Oklahoma City is a limestone series of 350-400 feet, individual beds ranging from 10 to 50 feet in thickness, interbedded with gray and brown shale and white sandstones. The top limestone of this series is referred to as Pawhuska and is the highest marker that is used for subsurface work. Other limestone beds are the Carmichael at 3,950 feet, the Oread at 4,100, the Tonkawa limestones at 4,250, the Checkerboard at 5,200, and the Oswego at 6,000. These are depths of the formations at the crest of the structure. With the exception of the Oswego limestone, their exact stratigraphic position in the type sections is still open to question (Fig. 2).

The normal stratigraphic sequence of rocks from the Mayes limestone of Mississippian age to the Arbuckle limestone of Cambro-Ordovician age was present originally in the Oklahoma City area, but all of them down to and including part of the Arbuckle were eroded on top of the structure. Upon the beveled edges of these formations a small amount of material disintegrated from them occurs in thin, scattered lenses. It is not important as a subsurface formation. In a few wells a peculiar black sand has been encountered in this zone. It is a clear quartz sand cemented with black petroleum residue. It suggests the existence of a pre-Pennsylvanian oil seepage in which the oil escaped from the Simpson sands. One well which was tested at a point where this sand was in the open hole blew out gas together with large quantities of black sand which from a distance looked like a column of oil.

OIL- AND GAS-BEARING FORMATIONS

Hoover sand.—An oil- and gas-bearing sand at about 4,000 feet, between the Carmichael and Oread limestones, has been correlated with the Hoover. It is 10-20 feet thick, but in many wells is composed chiefly

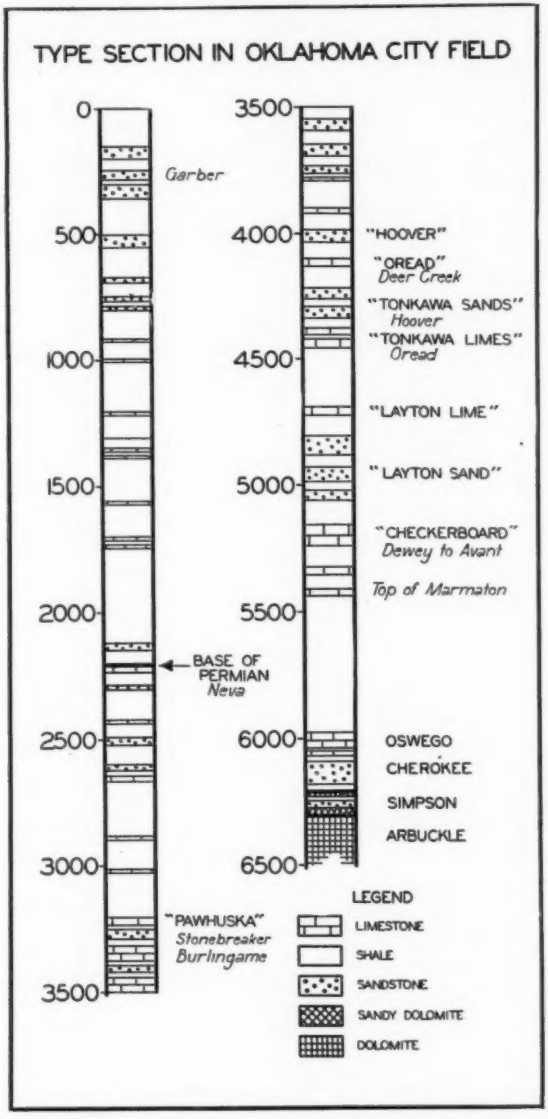


FIG. 2.—Type section of formations in Oklahoma City field. The approximate equivalents of parts of this section with the general type section, according to Robert Roth, are shown in smaller lettering. The thickness of the Simpson formation ranges from almost nothing near the top of the structure to about 800 feet on the flanks. Other younger formations ranging from Viola limestone to Mayes limestone inclusive are present in the surrounding area.

of broken sand or sandy shale. Two gas wells with initial production of 38,000,000 and 57,000,000 feet have been completed in this sand and some wells have had oil showings in it.

Tonkawa sands.—Two rather persistent sands, 20-50 feet thick, separated by 30-50 feet of shale, and a short distance below the Oread limestone, commonly show oil in cores. However, tests of them have been disappointing because in most wells they yielded salt water. The upper sand is known to be gas-bearing in a relatively small area at the top of the structure.

Layton sand.—A thick body of sands and broken sands containing irregular breaks of shale and sandy shale and having a total thickness of 200-300 feet composes the Layton sand series. The top is at a depth of 4,700-4,800 feet. This sand series serves as a reservoir for gas on the highest part of the structure.

Oswego limestone.—The Oswego limestone, ranging from 10 to 90 feet in thickness, is porous in parts, and gas showings come from it. This member and its sand equivalent (Wheeler) are productive of oil and gas in other fields of Oklahoma and Kansas, and it is probable that commercial production will be obtained from it at Oklahoma City.

Prue sand.—A body of brown impure micaceous sand ranging from almost nothing to 150 feet in thickness lies directly beneath the Oswego limestone or, in places, 50 feet below it. Showings of gas featured by threatened blowouts when some of the wells penetrated it show that it has good possibilities for furnishing gas production when the wells are plugged back from the lower formations.

Simpson sands.—Strata belonging to the Simpson formation occur under the Pennsylvanian beds in the Oklahoma City field except in an area of approximately 900 acres comprising the highest part of the structure, where the Arbuckle limestone is in contact with the Pennsylvanian (Fig. 3). By the processes of uplift and erosion the Simpson beds were worn away so that the oldest member of the formation pinches out against the Arbuckle limestone core. Down structure, the Simpson beds become increasingly thicker, and successively younger members of the formation are in contact with the capping Pennsylvanian beds.

"Wilcox" sand.—Approximately 550 feet stratigraphically above the Arbuckle limestone occurs 175-200 feet of Simpson sand to which the common name "Wilcox" has been applied. It is fine to coarse, fairly well assorted, subangular sand composed of frosted grains. The lowest 25 feet contains considerable greenish gray shale which probably represents the continuance of deposition, with interruptions, of the 50 feet

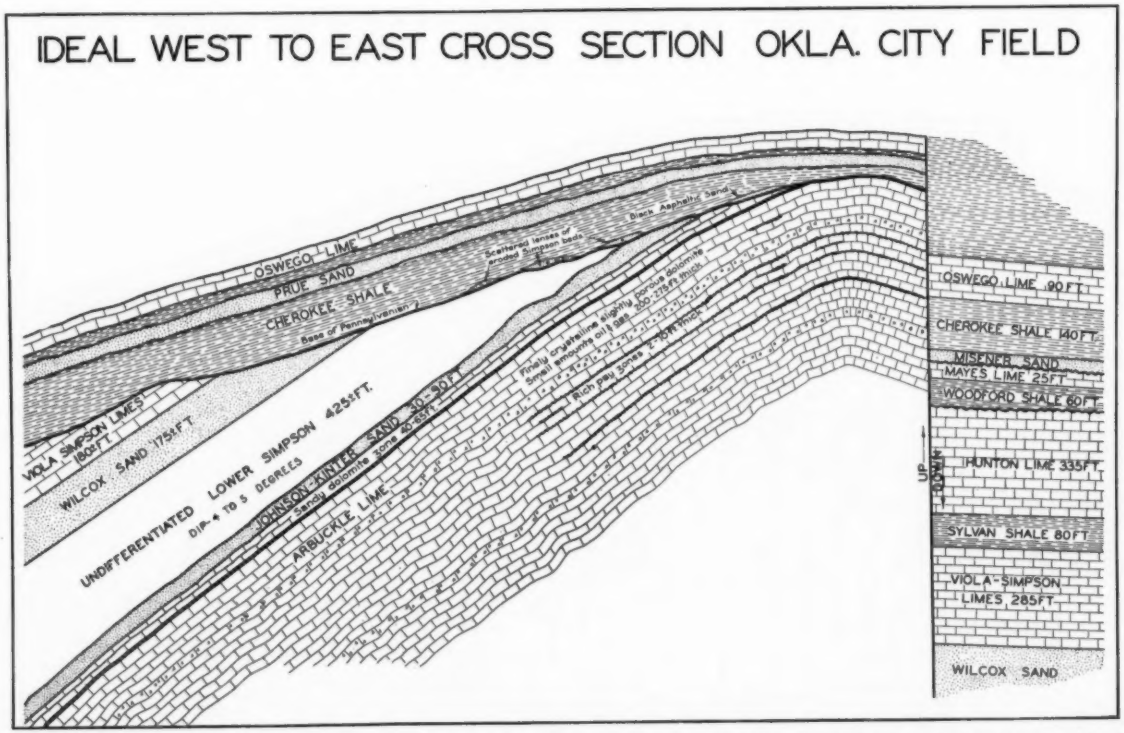


FIG. 3.—Type section showing relation of subsurface formations in Oklahoma City field. The section on the downthrown side of the fault was taken from the log of a well on the east side of the field. (Length of section about 3 miles.)

of dark green "greasy" shale below the "Wilcox" sand. Wells so far completed in the "Wilcox" have been uncommonly large, producing as much as 40,000 barrels per day.

In the lower 550 feet of the Simpson are several sandstones which serve as reservoirs for oil and gas. As is commonly the practice, these sands have been named after the farms on which they were first reached by the drill. The lowest in the section, the "Johnson" or "Kinter" sand, is 30-90 feet thick and occurs 40-65 feet above the Arbuckle limestone. It is a poorly assorted medium- to coarse-grained subangular sand that has yielded wells with a maximum initial production of 30,000 barrels. Along the narrow band of its former outcrop, gas wells with initial volume of 150,000,000 cubic feet were completed. Another sand, 30-40 feet thick, approximately 100 feet higher in the section, is called the "Mollman" or "Schoolland" sand. It is replaced in part by green shale or sandy dolomite and does not furnish such large wells as the "Johnson-Kinter" sand. Other uncorrelated sands, thought to be lenticular, and represented in places by slightly porous dolomitic sand or sandy dolomite, occupy a section estimated to be 300 feet thick between the "Schoolland" sand and the base of the "Wilcox" sand. These latter sands yield oil and gas, but in smaller quantities because of their small porosity. The initial production of wells completed in them varies from 1,500 to 3,000 barrels of oil and from 1,000,000 to 40,000,000 cubic feet of gas.

Arbuckle limestone.—The Arbuckle limestone, commonly termed the "Siliceous lime," furnishes spectacular wells in the Oklahoma City field. The accumulation of oil and gas in the Arbuckle at Oklahoma City is unique in that it is found in zones as much as 500 feet below the top of the formation, whereas in other "Siliceous lime" pools the oil and gas were concentrated in the upper few feet, directly under the unconformable contact with the capping formations. Cores and cuttings show the Arbuckle to be a dense to coarsely crystalline gray or brown magnesian limestone. Chert is a common constituent of some beds. Bands of green shale occur in places and local sandy beds are reported in some wells. Little progress has been made in interpreting the stratigraphy and structure of the Arbuckle. In general the upper 200-225 feet of beds beneath the Simpson is finely crystalline and below that depth the formation has the same general appearance but is more coarsely crystalline. In accordance with differences in texture recorded in different wells, the dip in the Arbuckle on the west flank of the structure varies from 4° to 5° and is practically the same as in the Simpson strata.

Records of the first few wells, drilled with standard tools, furnish evidence of the nature of the reservoir spaces in the Arbuckle. Production from the upper 200-275 feet varies from 1,000,000 to 5,000,000 cubic feet of gas and enough oil to fill 1,000-1,500 feet of the hole. An abrupt change in the productivity of the "lime" at the base of this non-porous zone resulted in production in one well of 100 barrels per hour in 3 feet of "pay." After drilling was continued 65 feet deeper with no increase, production was doubled in 2 feet. After deepening an additional 111 feet, another increase occurred. The production of another well was 312 barrels of oil and approximately 4,000,000 cubic feet of gas when a test was made after the "Siliceous lime" had been penetrated 270 feet. The production record of this well, as it was drilled deeper with standard tools, is here shown.

Total Depth (Feet)	*Penetration into "Siliceous Lime"*	*Production in 24 Hours*	
		Oil (Barrels)	*Gas (Cubic Feet)*
6,378	270	312	4,000,000
6,386	278	290	4,000,000
6,393	285	264	4,000,000
6,400	292	274	4,000,000
6,404	296	269	4,000,000
6,415	307	312	4,000,000
6,434	326	409	4,000,000
6,440	332	564	4,000,000
6,445	337	559	4,000,000
6,452	344	618	3,250,000
6,454	346	830	3,250,000
6,460	352	1,092	3,250,000
6,462	354	1,167	3,250,000
6,467	359	1,350	No record
6,473	365	1,458	3,500,000
6,483	375	1,441	3,500,000
6,505	397	1,507	3,600,000
6,517	409	1,452	3,600,000
6,532 (big increase 6,525-6,532)	424 ...	5,715	7,001,000

The largest part of the effective porosity in the "Siliceous lime" probably is confined to zones ranging from 2 to 10 feet in thickness. Roth[1] reports a chert conglomerate in the samples in which a notable increase in oil occurred in one well. This suggests porosity associated with disconformities. Loss of circulation of the rotary mud and a few places

[1]Robert Roth, personal communication.

where the drill pipe dropped several feet while drilling give evidence that cavities of considerable size exist. Secondary solution is the agent most likely to have caused this porosity. Authorities state that the porosity in dolomite (magnesian limestone) is caused by acid-bearing waters that dissolve both the calcium and the magnesium from the rock, but the former more readily. This process occurs between the surface and the ground-water table. The porous zones in the Arbuckle limestone may be the markers of stratigraphic breaks which occurred when the formation was above the sea. The suggestion has been offered that ground water may have circulated down through the dolomite and issued at the face of a cliff formed by the fault which has caused displacement of the Arbuckle along the east side of the field.

Water appeared in the discovery well 4 months after the well began to produce. The water and oil occur in the "lime" in a very irregular manner. Some wells yielded no water for a long time, although offsetting wells of equal penetration were yielding much water. Wells yielding both water and oil have had their oil production increased when deepened to another pay zone. A possible explanation of this condition postulates pay zones of varying thicknesses separated by impervious dolomite. If the oil were accumulated farther down the flanks of the structure in the narrow zones, a well drilled through one of the thicker pay zones, where it contained water, might find more oil in a deeper, thinner pay zone.

STRUCTURE

SURFACE STRUCTURE

The surface structure of the Oklahoma City field (Fig. 4) is an anticline 9 miles long and 4 miles wide within the lowest closing contour, which is 90 feet below the crest. The chief feature of the surface structure is the abrupt dip, equal to 150 feet per mile, on the northeast flank, where the dip would normally be 30 feet per mile in the opposite direction. This steep dip reflects the subsurface fault known to have caused displacement of formations up to and including the Oswego limestone.

SUBSURFACE STRUCTURE

The dips on the formations increase with their depth. Final development may show 500 feet of closure on the Oswego limestone. The major axis of the anticline shifts eastward so that at a depth of 6,000 feet the highest points are approximately ¾ mile from the highest points on the surface structure, giving the axial plane an inclination of 33°.

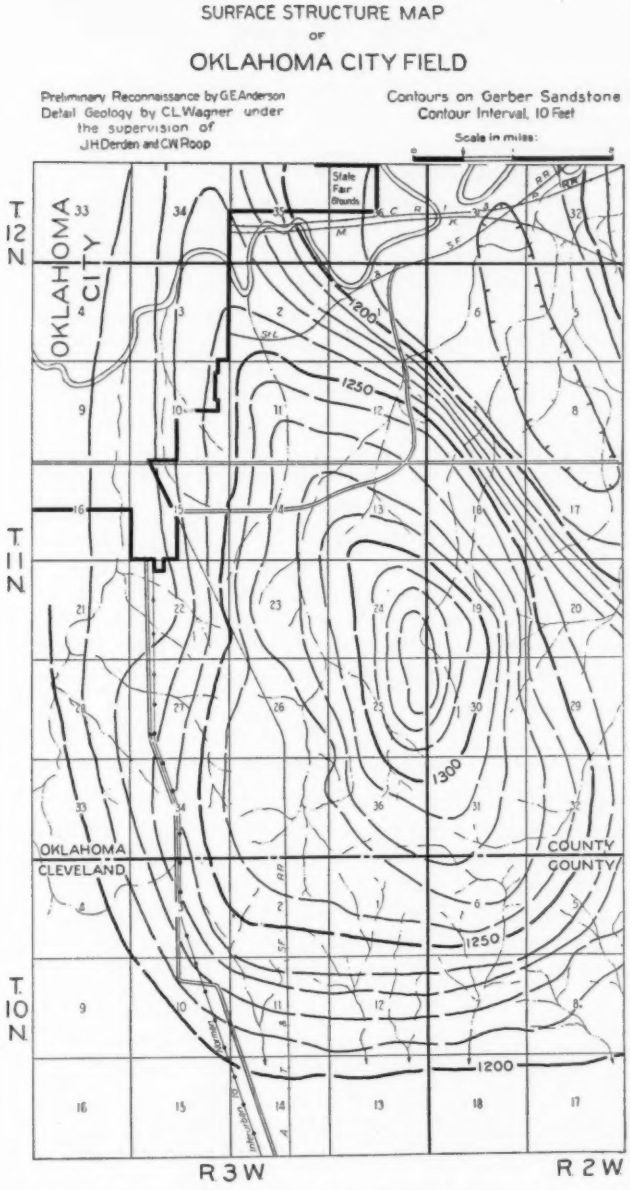


FIG. 4.—Surface structure map of Oklahoma City field. From "Oil and Gas in Oklahoma," *Oklahoma Geol. Survey Bull. 40*, Vol. II (1930), p. 454.

The steep east dip in the subsurface beds is terminated in the Oswego limestone and the lower formations by a nearly vertical normal fault.

The strike of the fault, approximately N. 27° W., is established to date from a point between the Slick-Prairie Oil and Gas Company's Hiddleston No. 2, SE. cor., Sec. 19, T. 11 N., R. 2 W., and Shell Petroleum Corporation's Petty No. 3, NE. cor., sec. 30, T. 11 N., R. 2 W., at one end, and Indian Territory Illuminating Oil Company's Pearl Trosper No. 1, NW. cor., Sec. 18, T. 11 N., R. 2 W., which well seemingly was drilled across the fault plane. In the Hiddleston No. 2, Sylvan shale was encountered at 6,815 feet and in the Petty No. 3, the offset, 660 feet south, Arbuckle limestone at 6,190 feet. The throw of the fault is estimated from these figures to be at least 2,200 feet. Knowledge of the extent of the fault will necessarily await further drilling. It is of primary interest in connection with the field, as it was a controlling factor in the formation of the great anticline and the accumulation of the oil and gas.

GEOLOGICAL HISTORY

As the structural relations in the Oklahoma City field are comparable in essential features with those of other structures of the same type in Oklahoma, this area must have experienced the same geologic history. The writer outlines this history only briefly, as it has been more fully described by others.[1]

Results of deep tests in the Blackwell and Garber fields, similar in structure to the Oklahoma City field, indicate a relatively thin section of Arbuckle limestone on top of the pre-Cambrian granite at Oklahoma City. This thinner section was deposited over a higher part of the granite floor, perhaps a ridge, which may have gained its relief through uplift. The porous zones in the Arbuckle, particularly the zone in which a chert conglomerate was found, may represent stratigraphic breaks when the formation was exposed to weathering.

In two wells, Slick's Glidden No. 2, SE.¼, SW.¼, SE.¼, Sec. 13, T. 11 N., R. 3 W., and Indian Territory Illuminating Oil Company's

[1]A. Travis, "Geology of Oklahoma County," *Oklahoma Geol. Survey Bull. 40-SS* (1930), pp. 20-24.

Wesley G. Gish and Raymond M. Carr, "Garber Field, Garber County, Oklahoma," *Structure of Typical American Oil Fields*, Vol. I (Amer. Assoc. Petrol. Geol., 1929), pp. 182-83.

Stuart K. Clark and James I. Daniels, "Relation Between Structure and Production in the Mervine, Ponca, Blackwell, and South Blackwell Oil Fields, Kay County, Oklahoma," *Structure of Typical American Oil Fields*, Vol. I (Amer. Assoc. Petrol. Geol., 1929), pp. 159-60.

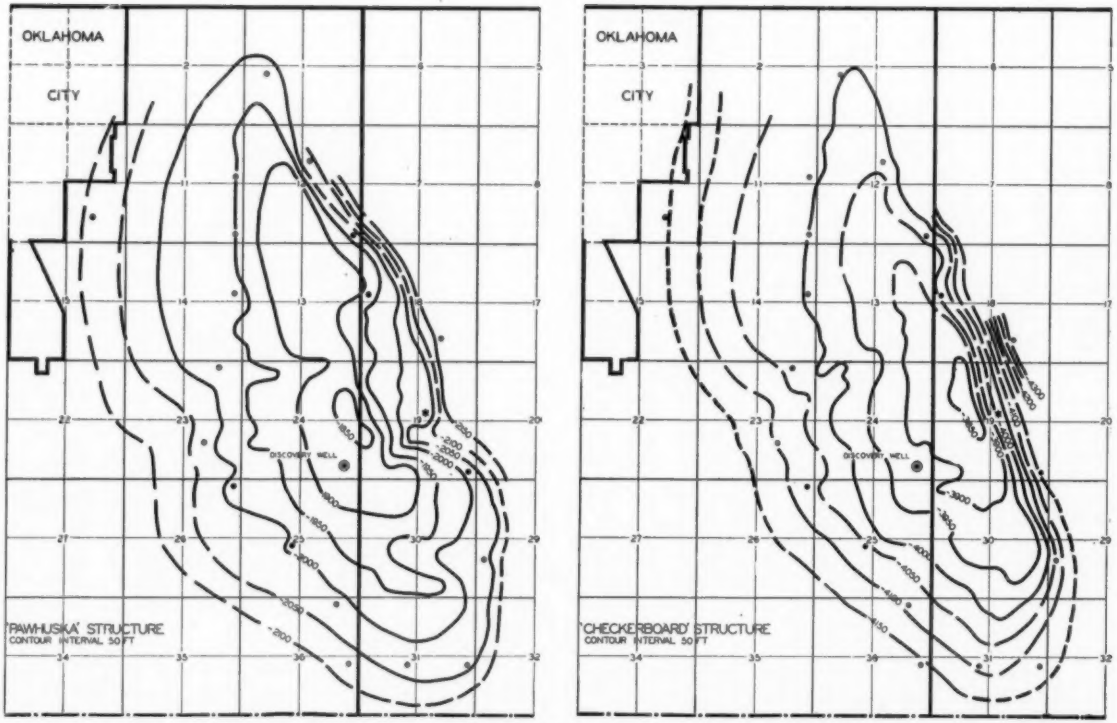


FIG. 5.—Subsurface maps of Oklahoma City field contoured on Pawhuska and Checkerboard limestones.

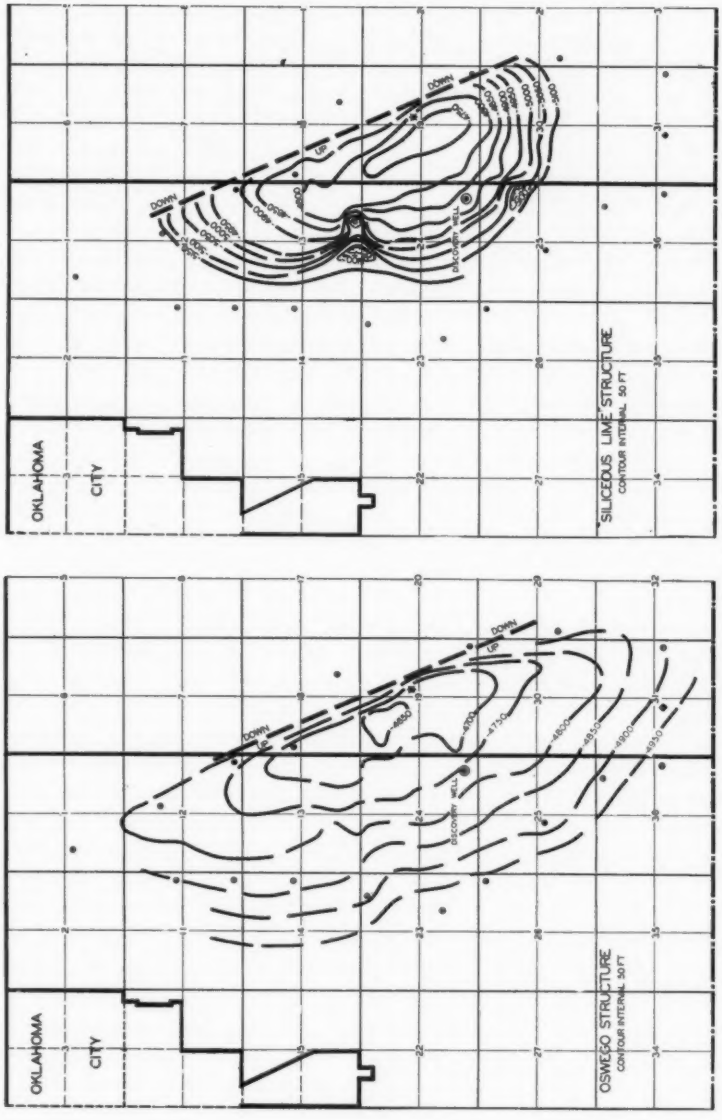


FIG. 6.—Subsurface maps on Oswego limestone and Arbuckle limestone. Contours on Oswego are on base of member.

Wilkie-Anderson No. 2, NE.¼, SE.¼, NE.¼, Sec. 25, T. 11 N., R. 3 W., the "Siliceous lime" was found at approximately 350 feet and 200 feet, respectively, lower than was indicated by the depths to the Arbuckle in surrounding wells. With these exceptions, the surface of the Arbuckle is smooth. The dips on the top, where it is covered by the Simpson, and on the "Johnson" sand, about 60 feet above the base of the Simpson, are practically equal in all directions. No evidence of a disconformity between the Arbuckle and a locally occurring basal ostracod-bearing limestone of the Simpson has been noticed. The evidence favors the supposition that the Arbuckle in this area was not exposed to erosion before the Simpson was deposited. About 550 feet of sandstones, green to black shales, and sandy dolomites, a 175-200-foot sandstone known as "Wilcox," the Simpson limestone, Viola limestone, Sylvan shale, Hunton limestone, Woodford shale, and Mayes limestone were deposited successively in the Oklahoma City area before another change in geological events (excluding minor oscillations of the sea) occurred.

The general elevation, accompanied by folding and faulting, that had such a marked effect on the Mid-Continent oil region at the end of the Mississippian period, developed the Oklahoma City structure. The strain resulting from a localized uplift was relieved by a fault. As the upthrown side was slowly elevated above the sea, the formations were worn away until finally the core of the structure, the Arbuckle limestone, was exposed in approximately 900 acres. The highest part of the area of uplift was probably an island that was base-leveled as rapidly as it emerged. Practically all the eroded material was removed, possibly by wave action, except small lenses of material derived from the Simpson beds. No widespread blanket of re-worked material such as a "detrital zone" is present. At the greatest point of displacement along the fault, as well as in the basins surrounding the anticline, a full section of sediments was protected from erosion. Succeeding Pennsylvanian and Permian sediments, beginning with the Cherokee shale, buried this truncated fold under essentially conformable beds. Rejuvenation of the faulting caused displacement of the Oswego limestone, which, in two pairs of wells at locations 660 feet apart, has 400 feet difference in elevation. The effect of the disturbance is shown by abnormal dip in the surface rocks.

DEVELOPMENT

The first eight wells commenced after the completion of the discovery well were located in the center of 40-acre tracts. The objective of this group of wells was the thick Layton sand at about 4,700 feet,

which gave encouraging evidence of prolific oil production from cores taken from Oklahoma City No. 1. The results of these early tests were disappointing, because the sand was found to be very irregular, much of it being only sandy shale, several of the wells were drilled too far into the sand and yielded only salt water, and others were gas wells. It was soon decided to drill all holes to the "lime pay" of the discovery well. During the course of rapid drilling to the "Siliceous lime" no effort was made to test properly the shallower Pennsylvanian sands, and their possibilities are still largely unknown. As soon as the first wells reached the Ordovician, the 7-inch casing was set a few feet below the top, and standard tools were substituted for rotary tools with the idea of testing the limestone carefully. The use of standard tools soon was found impracticable because, when pockets of gas confined under pressure of 2,300 pounds per square inch were tapped, the tools and drilling line were blown up and bridged tightly in the hole. Subsequently, rotary tools were used to drill the wells to their final depth.

The plan of developing the field by drilling on 40-acre locations was abandoned early because operators who had small holdings were unwilling to confine their drilling to this extent. The large initial production of the Arbuckle limestone wells and the discovery of highly productive Simpson sands on the flanks of the structure caused the adoption of 10-acre locations.

On March 10, 1930, there were 135 completed wells and 173 drilling wells or locations. Of the completed wells, 81 were in the Arbuckle limestone section of the field, at an average total depth of 6,550 feet, and their average initial production was 12,150 barrels. The largest of these, Indian Territory Illuminating Oil Company *et al.* Thomas-Fuzzell No. 1, gained the distinction of being the world's largest high-gravity oil well when it yielded approximately 43,000 barrels of 38° oil. On that date oil was being produced in 44 wells from the Simpson sand at an average depth of 6,400 feet. Their average initial production was 7,750 barrels.

OPERATING METHODS

Rotary rigs of the heaviest type, equipped with 123-foot steel derricks, are used in the Oklahoma City field. Batteries of four 125-horsepower and 300 pounds-working-pressure boilers furnish the power for each well. Three strings of casing are required. Surface pipe, 15½ inches in diameter, is set at 250-300 feet and cemented with 250-500 sacks of cement; 9-inch casing is cemented in the Checkerboard limestone at

5,200 feet with 1,500 sacks, and the 7-inch casing on top of the productive zone at 6,300-6,400 feet with 250 sacks. After the cement has properly set, at the end of 7 days, the plug is drilled out and the well is brought in by bailing the rotary mud down a sufficient depth so that the natural pressure of the well will clean the hole. After the well has flowed into the air until all the mud and water have been ejected, the oil and gas are diverted through separators and thence into tanks. The oil expelled under such great pressure from a depth of more than 6,000 feet requires extra heavy gates and fittings at the well head.

ANALYSIS OF OIL FROM ARBUCKLE LIMESTONE

Indian Territory Illuminating Oil Company's Oklahoma City No. 1, center, SE. ¼, SE.¼, Sec. 24, T. 11 N., R. 3 W.

Specific gravity, 0.837	A. P. I. gravity, 37.6°
Per cent sulphur, 0.16	Per cent water, none
Saybolt Universal viscosity at 70° F., 57 sec.	Pour point, 10° F.
Saybolt Universal viscosity at 100° F., 46 sec.	Color, green

APPROXIMATE SUMMARY

	Per Cent	*Specific Gravity*
Light gasoline (end point 212° F.)	6.7	0.688
Total gasoline and naphtha	26.1	0.737
Kerosene distillate	16.8	0.810
Gas oil	10.0	0.834
Non-viscous lubricating distillate	12.0	0.842–0.866
Medium lubricating distillate	6.7	0.866–0.876
Viscous lubricating distillate	0.0	....
Residuum	24.4	0.924
Distillation loss	4.0	....

ANALYSIS OF OIL FROM SIMPSON SAND

Indian Territory Illuminating Oil Company *et al* Bertha Johnson No. 1, NE.¼, NE.¼, NW.¼, Sec. 25, T. 11 N., R. 3 W.

A. P. I. gravity 38.9°

Oil from 6,374-6,375 feet ("Johnson" sand of lower Simpson, about 60 feet above Arbuckle limestone).

APPROXIMATE SUMMARY

	Per Cent	*Specific Gravity*
Light gasoline	8.1	0.745
Total gasoline	28.1	0.590
Kerosene	10.3	0.433
Gas oil	27.8	0.348
Lubricating distillate	5.8	0.292
Residuum	27.3	0.223

ANALYSES OF WATER FROM ARBUCKLE LIMESTONE

	Indian Territory Illuminating Oil Company's Oklahoma City No. 1, center SE.¼, SE.¼, Sec. 24, T. 11 N., R. 3 W. Total depth, 6,496 feet.	Indian Territory Illuminating Oil Company's Sonora Bodine No. 1, NW. cor., Sec. 30, T. 11 N., R. 2 W. Total depth, 6,474 feet.
	Parts per Million	*Parts per Million*
Calcium	12,030	11,590
Magnesium	2,065	2,090
Sodium	58,730	60,580
Chloride	117,620	119,800
Sulphate	276	244
Bicarbonate	74	47
Carbonate	None	None
Total solids	190,765	194,351
Specific gravity	1.1532	Specific gravity 1.153

SUBSURFACE DISTRIBUTION OF PRE-MISSISSIPPIAN ROCKS OF KANSAS AND OKLAHOMA[1]

HUGH W. McCLELLAN[2]
Tulsa, Oklahoma

ABSTRACT

The first recorded evidence of beds of pre-Mississippian age in Kansas was in 1908. These range in age from pre-Cambrian to Devonian, but do not crop out in the state. Wells drilled for oil since 1925 have furnished much information regarding the character and extent of these older Paleozoic rocks. Their present areal distribution is the result of a long history of repeated earth movements of regional extent. The two most important movements occurred between Devonian and Mississippian and in post-Morrow time. The duration of erosion periods was progressively greater toward the northwest.

Although the paper principally concerns Kansas, where the data have been accumulating for 4 years, an effort has been made to present new data in Oklahoma and bring the map up to date. The map represents the areal geology of most of Kansas and Oklahoma as it would appear if all the sediments were removed down to the base of the Mississippian.

INTRODUCTION

Sedimentary rocks of pre-Mississippian age do not crop out in Kansas, and their existence, although suspected, was not proved until they were discovered by the drill. Thus the determination of the pre-Mississippian stratigraphy is entirely dependent on well cuttings and cores and on long-range comparisons with outcrops hundreds of miles away in adjacent states. In Oklahoma the entire section is exposed in the Arbuckle Mountains and the outcrops have furnished a check for subsurface data gained in oil-field development. Deep wildcat wells in Kansas, particularly in the west ranges, were not drilled until several years after the subsurface stratigraphy had been fairly well determined in Oklahoma.

Schrader,[3] in 1908, recorded beds below the Mississippian, encountered in a well near Caney, Kansas, but it is probable that his correlations are erroneous.

[1]Read before the Association at the New Orleans meeting, March 22, 1930. Manuscript received by the editor, September 16, 1930.

[2]Geologist, Burke-Greis Oil Company.

[3]F. C. Schrader, "Independence, Kansas," *U. S. Geol. Survey Folio 159* (1908), p. 4.

As early as 1921, Aurin, Clark, and Trager[1] had traced the Tyner formation and an Ordovician siliceous limestone (now known to be Arbuckle) northward from Oklahoma into Kansas along the Granite ridge as far as the north line of Chase County. Because nearly all the wells available at that time were on a pronounced subsurface structure, only the lower part of the Ordovician beds of Kansas was represented, all the section between the Tyner formation and the basal Mississippian having been removed by post-Devonian erosion.

In March, 1926, Udden[2] reported green shales of Black River (Decorah) age from a well drilled by the Valerius Oil Company in Russell County in 1924. A bryozoan fauna found in the shale was examined by T. E. Savage of the University of Illinois, who made the age determination, and this conclusion was supported by Udden and P. V. Roundy, who considered the fossils to be definitely Ordovician.

The writer's first contact with a pre-Mississippian section in Kansas occurred in November, 1926, while examining drill cuttings from the Empire Gas and Fuel Company's Woodbury No. 1, Sec. 14, T. 9 S., R. 4 E., Riley County, which was commenced in 1924 and completed in 1925. It was with some surprise that a bright green shale was encountered between 2,635 and 2,645 feet in depth, lithologically identical with the Tyner shale of Oklahoma. A bryozoan fauna was found in the shale, chiefly *Escharopora* and *Rhinidictya cf. mutabilis*, thus strongly suggestive of Decorah age.

This clue led to the examination of other old deep well samples and to an unpublished report dated December 14, 1926, in which the following statement was made.

> A study of all the samples available. . . . leads me to the conclusion that there is a pre-Chattanooga section in Northern Kansas, north of T. 16 S., which corresponds to the pre-Chattanooga section of Oklahoma.

Late in 1926 Twenhofel[3] reported the occurrence of Decorah fossils from a green shale in several deep wells in Russell County. About the same time the present period of active wildcatting in western central Kansas began, with the result that the available data increased rapidly.

[1] F. L. Aurin, G. C. Clark, and Earl A. Trager, "Notes on the Subsurface Pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (March-April, 1921), pp. 117-53.

[2] Jon A. Udden, "Occurrence of Ordovician Sediments in Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 6 (June, 1926), pp. 634-35.

[3] W. H. Twenhofel, "Ordovician Strata in Deep Wells of Western Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 1 (January, 1927), pp. 49-53.

Early in 1928 Barwick[1] published a description of the stratigraphy and structure of north-central Kansas, in which new names were proposed for the several stratigraphic units. In 1929 Edson[2] published a correlation of these rocks with those of surrounding states.

The construction of a map showing the subsurface distribution of the pre-Mississippian rocks in Kansas naturally follows from the work of White[3] in Oklahoma. The map of northeastern Oklahoma is largely that in White's paper, with some revisions and additions necessitated by new data, particularly in Cherokee and Adair counties.[4] The Sylvan exposure in Seminole County is after Levorsen,[5] and the area just north of the Arbuckle Mountains is largely after Dott.[6] The work of Roth[7] is followed northwest of the Arbuckles, near the Robberson field.

The writer is greatly indebted to Frank T. Clark, of Bartlesville, for his active interest in this map since its beginning in 1926, and for the delineation of some of the older producing areas along the Granite ridge.

Except in the areas here mentioned, the control for the map is largely the result of well-sample examinations and subsurface work by the writer during a period of 4 years.

The writer wishes to express his appreciation to the following, for information, criticism, and suggestions: Sidney Powers, Luther H. White, Ira H. Cram, Elizabeth Isaacs, Robert H. Dott, G. S. Lambert, A. I. Levorsen, Charles Ryniker, Howard S. Bryant, T. C. Hiestand, Robert L. Kidd, and Richard Hughes.

STRATIGRAPHY

PRE-MISSISSIPPIAN

In studying the stratigraphy of the pre-Pennsylvanian rocks in Kansas it is noticeable that the section represented in the Salina and

[1]John S. Barwick, "The Salina Basin of North-Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1928), pp. 177-99.

[2]Fanny C. Edson, "Pre-Mississippian Sediments in Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 5 (May, 1929), pp. 441-58.

[3]Luther H. White, "The Subsurface Distribution and Correlation of the Pre-Chattanooga ('Wilcox' Sand) Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40-B* (June, 1926).

[4]Ira H. Cram, "Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull. 40-QQ* (May, 1930), Pl. 1.

[5]A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (March, 1928), Fig. 3.

[6]Robert H. Dott, unpublished data.

[7]Robert Roth, "The Robberson Field," *Oklahoma Geol. Survey Bull. 40-K* (May, 1927), Fig. 6, p. 42.

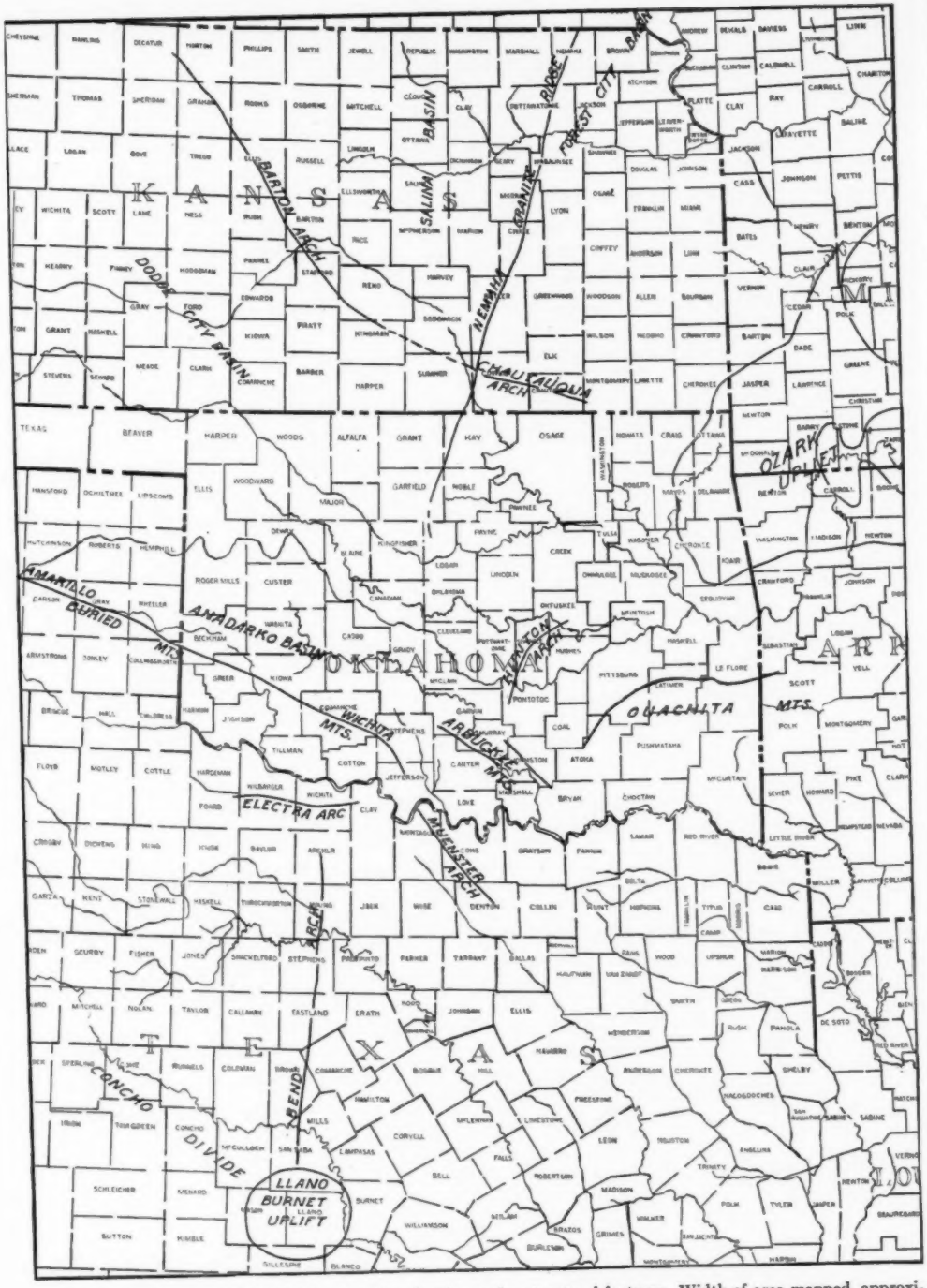


FIG. 1.—Index map of Mid-Continent region showing major structural features. Width of area mapped, approximately 490 miles

Forest City basins (Fig. 1) is more closely allied with the rocks of Iowa and Missouri than with those of Oklahoma.

PRE-CAMBRIAN

Granites and schists have been reached in many wells in Kansas. They were exposed by erosion along part of the Granite ridge and in small areas in Norton, Decatur, Russell, and Rush counties before Pennsylvanian deposition. These basement rocks have been considered pre-Cambrian in age by Moore[1] and other writers.

BASAL SANDSTONE

In a large part of Kansas, as elsewhere, the sedimentary series begins with a basal sand, the product of erosion during the base-leveling of the basement rocks. The sand is coarse, feldspathic, and contains quartz grains ranging in shape from angular to fairly well rounded, commonly associated with considerable muscovite and biotite. Ordinarily it ranges from 30 to 100 feet in thickness, but 4 miles southeast of Ellsworth it is more than 1,000 feet. This sand was probably stratified by the Cambrian sea in southeastern Kansas and is approximately correlated with the Reagan and La Motte, as shown by Edson,[2] but in most of Kansas it is probably Ordovician in age, or possibly younger in a few places.

ARBUCKLE LIMESTONE

The Arbuckle underlies the entire state, so far as present data show, except in a few small areas. Its absence may be due to non-deposition or to post-Arbuckle, post-Devonian, or post-Mississippian erosion. The first or second condition is illustrated in T. 8 S., R. 4 E., where the Simpson rests on granite, and the third or fourth condition is shown in small areas in western Norton and eastern Decatur counties, northeast of LaCrosse, at Gorham, and on the crest of the Granite ridge southward from the Nebraska line into Wabaunsee County, and just west of Cottonwood Falls.

Decker[3] has measured approximately 8,000 feet of Arbuckle limestone in the Arbuckle Mountains, but in southeastern Kansas it is ordinarily about 1,000 feet thick, and on the Barton arch it does not exceed 300 feet. At El Dorado, on the Granite ridge, it ranges from 365 to 1,100 feet in thickness.

[1]R. C. Moore, "Geologic History of the Crystalline Rocks of Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), p. 98.

[2]Fanny C. Edson, *op. cit.*

[3]Charles E. Decker, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Circular 15* (January, 1928), p. 12.

On the Barton arch the limestone is chiefly white and dolomitic and is characterized by oölitic chert and interbedded coarse sands, angular to fairly well rounded. A similar zone is reported by Decker as occurring about 3,400 feet below the top of the formation. If these zones are correlative, approximately 3,400 feet of upper Arbuckle limestone is missing on the Barton arch. In addition there is about 4,000 feet of the lower Arbuckle which is not represented in this area because of overlap.

In southern and eastern Kansas the Arbuckle is a fine-grained brown dolomite, cherty in some places.

That part of the Arbuckle represented in Kansas, probably near the middle of the formation, may be considered lower Canadian or upper Ozarkian.

The Arbuckle limestone has been generally known as the "Siliceous lime"[1] in Kansas. It can be traced northward from Oklahoma by means of well-log correlations so that there is no doubt of its continuity. It is primarily a dolomitic limestone and is only locally siliceous. Several other formations are more siliceous, notably the Mississippian. The term "Siliceous lime" is therefore inappropriate and misleading and it is suggested that it be dropped.

SIMPSON FORMATION

The Simpson in Kansas is very similar to that in Oklahoma, consisting of bright bluish green shales, white limestone and dolomite, and rounded sands interbedded. Its thickness ranges from 50 to 150 feet. In Riley County it contains a bed of oölitic hematite about 25 feet thick. White[2] differentiated three divisions of the Simpson on his pre-Chattanooga map of northeastern Oklahoma, namely, the Burgen sand, Tyner shale, and "Wilcox" sand. Edson[3] has distinguished the "Wilcox" sand in Kansas by means of heavy mineral analyses and found it only in a limited area. It probably does not extend farther north than the El Dorado field.

Since the "Wilcox" sand closely resembles several similar sands in the Simpson formation, the oil fraternity commonly applies the name to any Simpson sand. For this reason, would it not be well to abandon the name entirely?

In tracing the Simpson northward from Oklahoma it is found to become much thinner and it is not practicable to distinguish different

[1]John S. Barwick, *op. cit.*, p. 186.

[2]Luther H. White, *op. cit.*

[3]Fanny C. Edson, *op. cit.*, p. 451.

members. On the accompanying map (Fig. 2) it is represented as a single lithologic unit. With more research it may be possible to define the limits of the different divisions.

Many occurrences of fossils in the Simpson in Kansas have been noticed, and each indicated upper Black River age (upper Simpson). The Simpson sea, therefore, must have been overlapping progressively northward, so that only the upper Simpson is represented in most of Kansas.

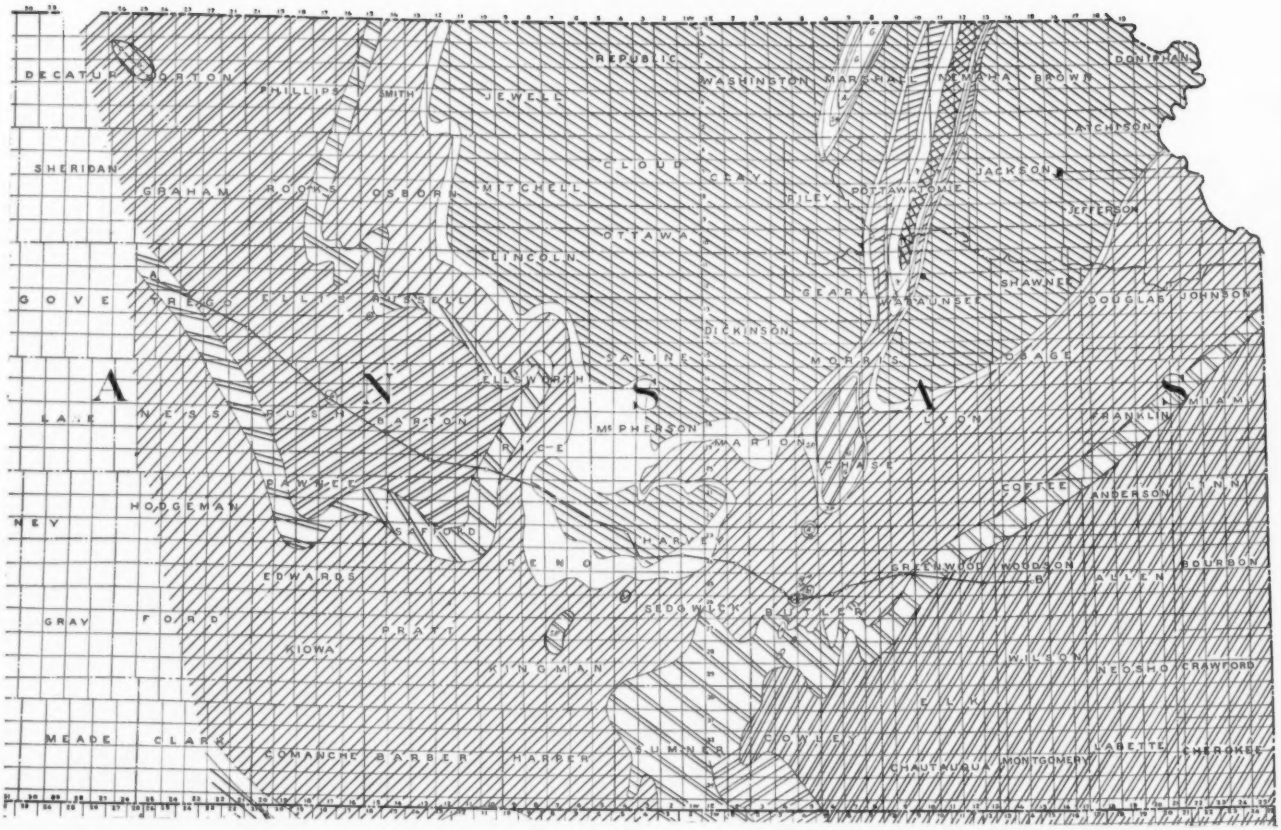
URSCHEL LIMESTONE

Overlying the Simpson formation is a bed of limestone, ranging from 100 to 180 feet in thickness where typically developed in the Salina basin. Thinning due to post-Ordovician erosion is noticeable toward the crest of the Barton-Chautauqua arch. In central Kansas the limestone is only 10-30 feet thick. In some places, as in Rooks, Smith, and Marion counties, all of the Urschel is missing, but there is a limestone of Black River age at the top of the Simpson. This can only be determined by paleontological evidence, and the data at present are not sufficient to permit the separate mapping of this limestone. The Urschel as mapped, therefore, includes in places some upper Simpson limestone, just as the Viola does on the Oklahoma part of the map.

In central and southern Kansas, approximately the lower 40 feet of the Urschel is very similar lithologically to the Fernvale (lower Richmond) of Oklahoma. It is ordinarily a coarsely crystalline, white limestone, somewhat mottled with black material between the crystals. In a large part of central Kansas only this lower bed remains. In many places it is very porous because of pre-Mississippian weathering and forms a satisfactory oil-producing horizon. This limestone was cored by the Empire Oil and Refining Company in the El Dorado field, where it was 20 feet thick. Some fossils which were obtained were sent by R. L. Kidd[1] to E. R. Cumings, of Indiana University, who considered them to be of Richmond age. Lithology and fauna thus indicate that the lower, coarsely crystalline bed of the Urschel limestone is Fernvale.

The upper part of the Urschel consists of both finely crystalline and dense cherty dolomitic limestone. In Barber and Pratt counties the chert predominates. Because of its position above probable Fernvale limestone, this bed seems to be younger than any bed in the Viola limestone.

[1]R. L. Kidd, "Richmond Fossils in Kansas Viola," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), pp. 1351-52.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SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
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ROOKS
OSBORNE
MITCHELL
CLOUD
CLAY
RILEY
POTTAWATOMIE
JACKSON
ATCHISON
JEFFERSON
OTTAWA
LINCOLN
GOVE
TREGO
ELLIS
RUSSELL
DICKINSON
GEARY
WABAUNSEE
SHAWNEE
DOUGLAS
JOHNSON
SALINE
MORRIS
OSAGE
MIAMI
FRANKLIN
ELLSWORTH
MCPHERSON
MARION
CHASE
LYON
COFFEY
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STAFFORD
HARVEY
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GREENWOOD
WOODSON
ALLEN
BOURBON
EDWARDS
SEDGWICK
BUTLER
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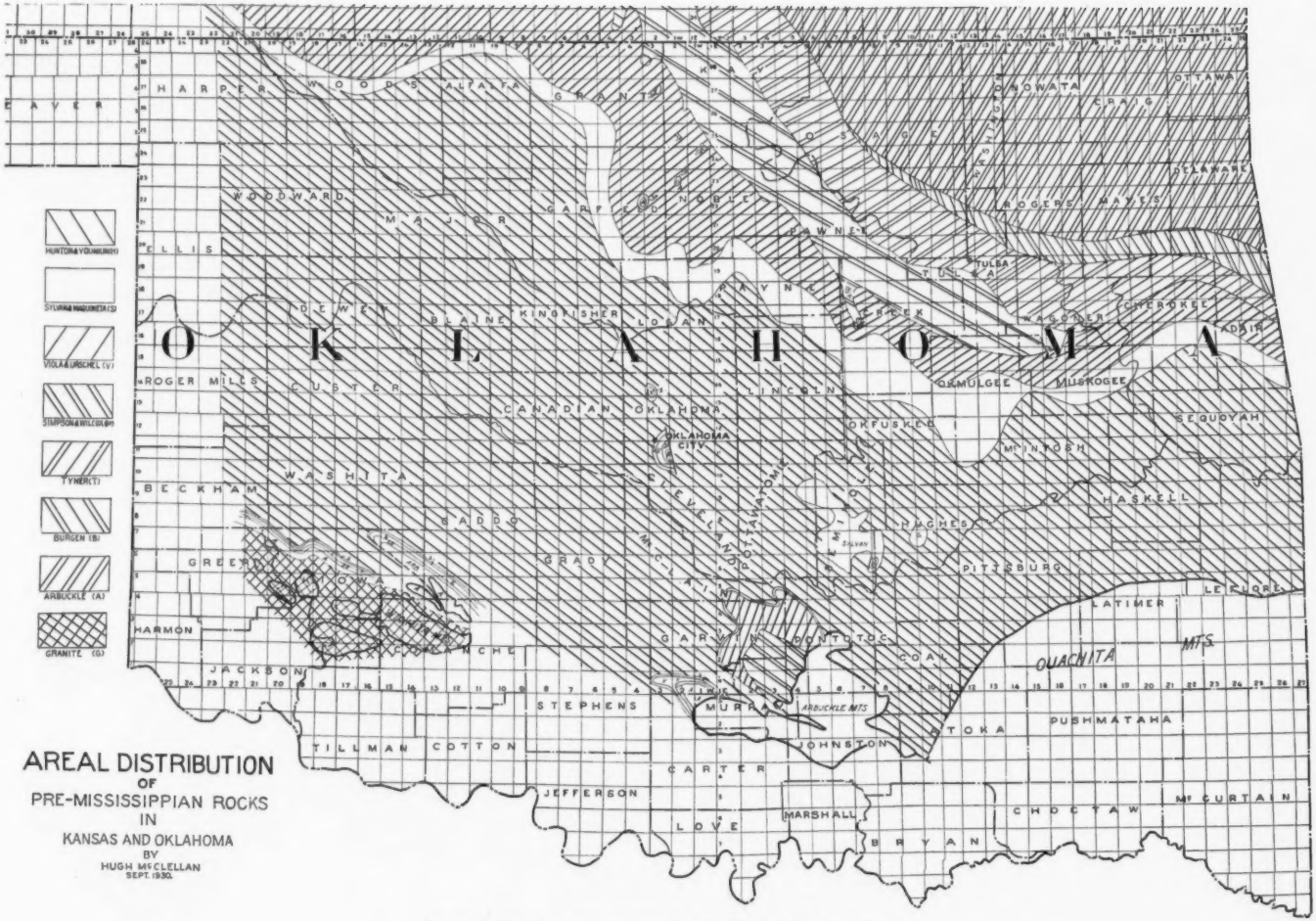

FIG. 2.—Width of area mapped, approximatelv 318 miles.

In Riley County, northern Kansas, there is only about 30 feet of light brown dolomite overlying 20 feet of the coarsely crystalline phase, below which is 110 feet of both dense and finely crystalline cherty limestone. If a correlation on the basis of lithology can be relied upon, this suggests that the upper bed and the Fernvale are feathering out toward the north, and an older bed, probably Galena in age, appears and thickens toward the north.

The limestone unit here discussed was named the Urschel limestone by Barwick,[1] and, as its age and correlation are not fully determined, it seems best to retain the term. The Urschel limestone is probably not entirely correlative with either the Galena of Iowa or the Viola of Oklahoma.

MAQUOKETA SHALE

The Maquoketa is a greenish gray dolomitic shale, ranging in thickness from 30 to 75 feet. It is thickest and most dolomitic in the southern part of the Salina basin and thins northward. In southwestern Iowa wells have shown it to be missing entirely.

In many places the lithology of the Maquoketa shale is almost identical with that of the Kinderhook, and where the Younkin limestone is not present between them it is ordinarily impossible to fix the contact between the two shales.

The stratigraphic position and lithology of this shale, as well as some fragmentary fossils which it contains, permit little doubt of the correctness of its correlation with the Maquoketa, Sylvan, and Cason shales, suggested by Barwick[2] and by Edson.[3]

YOUNKIN LIMESTONE

The limestone overlying the Maquoketa shale is gray and white, finely crystalline, mostly dolomitic, and in places cherty. The thickness ranges from 200 to 400 feet in the Salina basin, and is 500 feet in the Forest City basin (Fig. 1). Locally, just west of the Granite ridge, it contains at least one lens of coarse, rounded sand about 65 feet below the top. The Younkin is known only in the Salina and Forest City basins.

The mapping of the erosional remnant of Younkin in Harvey and Reno counties has been particularly difficult because the Maquoketa and Kinderhook are lithologically very similar and both may contain

[1] John S. Barwick, *op. cit.*, p. 184.

[2] *Idem.*

[3] Fanny C. Edson, *op. cit.*

dolomite beds which, on the driller's log, may be mistaken for Younkin. Much of the stratigraphic evidence seems to indicate Kinderhook age for both the greenish gray shales and the included dolomites, but this has been contradicted by the paleontological evidence of the Gypsy Oil Company's Hege well described in this paper.

Evidence which points to Kinderhook age in this area for the entire section between the "Mississippi lime" and the Urschel limestone may be summarized as follows.

1. The interval between the base of the "Mississippi lime" and the Urschel remains nearly constant at about 250 feet regardless of the presence or absence of the supposed Devonian limestone. This was pointed out by Hiestand[1] and shown in his north-south cross section.

2. In the Helmerick and Payne well, Sec. 22, T. 21 S., R. 3 W., casing was set in the limestone and *Sporangites huronense* was found in the shale below the limestone.

3. One dolomite bed, and in places two, occur in the Kinderhook shale in the Valley Center pool and in Kingman County, with typical Chattanooga shale at the base.

4. The Urschel is eroded and only the lower coarse limestone remains. There is very little erosion at this horizon between the Sylvan shale and Fernvale limestone in Oklahoma.

Evidence which indicates that the dolomitic limestone in the green shales between the "Mississippi lime" and the Urschel is of Siluro-Devonian age, is as follows.

1. A sand, which is very similar to Misener or Sylamore, is commonly present on top of the limestone.

2. Paleontological evidence, described in this paper, indicates Devonian or Silurian age for the limestone.

Fossils are very scarce in the northern Younkin, but recently a core was taken by the Gypsy Oil Company in its Hege No. 1 in Sec. 13, T. 22 S., R. 2 W., Harvey County, Kansas, which contained a very fossiliferous layer. The limestone, which was encountered at a depth of 3,330 feet, was about 80 feet thick, consisting of white sandy limestone, slightly cherty in the upper 40 feet, underlain by 40 feet of dolomitic limestone, finely granular and very porous because of the leaching out of fossils and other calcareous material. The fossiliferous layer occurred at 3,397-3,400 feet. Charles Ryniker, of the Gypsy Oil Company, considered the fossils to be of Devonian age and sent a part of the core to R. C. Moore, state

[1]T. C. Hiestand, "Voshell Area in McPherson County," *Oil and Gas Jour.* (June 5, 1930), p. 36.

geologist of Kansas. Although the fossils were poorly preserved, Moore succeeded in identifying ten genera and six species, regarding which he states:

> I should say at once and with definiteness that the dolomite in the Hege well is certainly not Kinderhook. Indeed I am inclined to lean toward Silurian rather than Devonian.[1]

Because the Siluro-Devonian limestone in the Hege well is an erosional remnant, it would not be surprising if only the lower or Silurian part of the Younkin were represented here.

The writer holds the opinion that although the limestone in the Hege well is Siluro-Devonian in age, very probably much of the limestone which seems to be at the same horizon in adjacent areas is, in reality, Kinderhook in age. New evidence may greatly decrease the size of the erosional remnant of Younkin limestone as mapped in the south end of the Salina basin (Fig. 2).

Cores and samples taken from a deep well near Forest City, Missouri, which is only a few miles from the northeastern corner of Kansas, were studied by Ulrich,[2] who identified 75 feet of Upper Devonian limestone, 330 feet of Middle Devonian, cherty, dolomitic limestone, and 140 feet of Silurian (Lockport) dolomite. Evidently much of the Younkin in northeastern Kansas consists of beds younger than the Hunton limestone of Oklahoma, with a lower member approximately equivalent to the Henryhouse member of the Hunton.

Because of the aforementioned uncertainties in correlation, it seems best to retain the name Younkin suggested by Barwick.[3]

MISSISSIPPIAN

MISENER SAND

In the Valley Center pool, north of Wichita, and in the Voshell pool in T. 21 S., R. 3 W., and between these two places in Harvey and Sedgwick counties and extending westward into Reno County, a sand occurs just below the Kinderhook shale. The quartz grains are fine, angular to rounded, and commonly cemented by dolomite. The thickness ranges from 3 to 15 feet.

This sand occupies the stratigraphic position of the Misener and Sylamore sandstones, and like them occurs in isolated lenses on the old

[1] R. C. Moore, letter of August 23, 1930.

[2] E. O. Ulrich, reported in *Missouri Bur. Geol. and Mines Pub.*, Vol. 16 (1922), 2d ser., p. 196.

[3] John S. Barwick, *op. cit.*, p. 184.

eroded pre-Mississippian surface. It is an oil reservoir in some places, but has never been of much commercial importance in Kansas.

KINDERHOOK AND CHATTANOOGA SHALES

The Chattanooga shale can be traced from Oklahoma into Kansas as far northward as Marion County, where it seems to lose its identity in the lower part of a much thicker light greenish gray shale which is correlated with the Kinderhook of Iowa. The same species of plant spores is found in both shales.

Near the Kansas-Oklahoma line, black Chattanooga shale is found above, below, and in the middle of, gray dolomitic shales, as in the Marland's Webb No. 1, Sec. 2, T. 27 N., R. 3 W., Grant County, Oklahoma, and in the Gypsy's Williams No. 1, in Sec. 16, T. 35 S., R. 3 W., Sumner County, Kansas. Farther north greenish gray shales appear above dark gray and black shales and dolomites, as in Allison-Fitzwilliams' Gesell No. 1, Sec. 24, T. 26 S., R. 1 W., and as in Sec. 9, T. 30 S., R. 2 W., and Sec. 36, T. 32 S., R. 5 E. Northward the Kinderhook is almost entirely greenish gray shale, but the black Chattanooga persists at the base as far north as the Empire's Seibel No. 1 in Sec. 28, T. 20 S., R. 2 E., and in the Voshell pool.

The Kinderhook in northern Kansas ordinarily ranges from 150 to 200 feet in thickness, but in Harvey County, where the Younkin erosional remnant occurs, it is, in some places, only 30 feet. In such places it is probable that the position of the upper part of the shale is taken by limestone of Kinderhook age. This change seems to occur also near the southern boundary of Kansas, where the lower member of the "Mississippi lime," about 40 feet in thickness, is non-cherty and in places separated from the limestone above by a thin, greenish-gray shale.

It seems probable, therefore, that only the lower part of the Kinderhook shale is equivalent to the Chattanooga, a conclusion which is substantiated by the accepted correlations in Illinois and Missouri.

MISSISSIPPIAN LIMESTONE

The upper part of the Mississippian in Kansas consists of cherty white or light tan, finely crystalline limestone, which ordinarily shows evidence of prolonged weathering and concentration of chert at the top. As already mentioned, a non-cherty member occurs at the base of the limestone.

Either through non-deposition or post-Mississippian erosion, all of the Mississippian is missing over the Barton arch and the northern part of the Granite ridge. It is therefore to be expected that different

parts of the Mississippian occur in different parts of Kansas. Buchanan's[1] work indicates that the Boone is to be found only in the southeastern quarter of the state. At the north and west are limestones of St. Louis and Chester age. Recent deep wells in Clark County, Kansas, and northwestern Oklahoma have penetrated as much as 1,600 feet of Mississippian limestone, of which at least the upper 400 feet is of Chester age, according to Roth,[2] who has studied the paleontologic evidence.

PENNSYLVANIAN

PENNSYLVANIAN BASAL CONGLOMERATE

Erosion affecting the distribution of the pre-Mississippian rocks did not cease until the Pennsylvanian sea had completely transgressed the area. The Pennsylvanian basal conglomerate must, therefore, be considered.

This conglomerate, which was first described by Moore,[3] consists chiefly of residual chert and dark red clay, with some quartz grains and thin beds of dense limestone. Only a little red clay represents it on the crest of the Granite ridge and there is very little evidence of it east of the ridge. The conglomerate is best developed on and near the Barton arch. The thickness ordinarily ranges from 40 to 100 feet, but on the west side a thickness of 235 feet was encountered in the Phillips' Spitz No. 1 in Sec. 24, T. 12 S., R. 25 W., and other wells farther south show similar thicknesses.

In the Welch pool, T. 20 S., R. 6 W., in Rice County, the conglomerate is nearly all chert, the lower part of which may be weathered chert in place. This is the type locality of the Welch chert of Moore.[4] As shown by cuttings from the wells mentioned in the following discussion, there is no Pennsylvanian shale below the Welch chert at this locality.

Samples from the Phillips Petroleum Company's Leona No. 1, NE.¼, NW.¼, NE.¼, Sec. 3, T. 21 S., R. 6 W., showed the following section: 3,335-3,360 feet, red, yellow, and white variegated shale; 3,360-3,374, dark red residual clay and white and yellow weathered chert; 3,374-3,439,

[1]George S. Buchanan, "The Distribution and Correlation of the Mississippian of Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 12 (December, 1927), p. 1315, Fig. 4.

[2]Robert Roth, oral communication.

[3]R. C. Moore, "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), p. 206.

[4]R. C. Moore, *op. cit.*, p. 212.

tan weathered chert; 3,439-3,441, light bluish green clay shale containing some rounded quartz grains; 3,441-3,458, white crystalline limestone, chert 10 per cent, top of Mississippian in place; and 3,458-3,504 feet, typical Kinderhook shale.

In the Prairie Oil and Gas Company's W. L. Welch No. 3B in NW.¼, NE.¼, SW.¼, Sec. 35, T. 20 S., R. 6 W., Rice County, Kansas, the base of the Mississippian limestone was found at the depth of 3,508 feet. Below was typical Kinderhook shale to 3,710 feet. *Sporangites huronense* (Kinderhook) was found at 3,555-3,575, 3,635-3,640 and 3,680-3,685 feet. Urschel limestone underlies the Kinderhook.

At the type locality the Welch chert consists of residual weathered chert and geest,[1] of which at least the upper part was stratified by the Pennsylvanian sea. It is underlain by Mississippian limestone in place. The Welch chert is therefore correlative with the Pennsylvanian basal conglomerate as previously discussed. Perhaps the term "Welch conglomerate" would be more descriptive to apply to the entire extent of this formation.

At Gorham, west of the town of Russell, where the Pennsylvanian rests on granite, the basal conglomerate oil-producing zone is feldspathic and has been called the "Gorham sand" or "Gorham conglomerate."

In the El Dorado field the Stapleton oil zone occupies the same stratigraphic position, but there is very little detrital material between the Pennsylvanian and the truncated Ordovician rocks. The oil is found in the weathered surface of the older rocks.[2]

Well preserved fossils, particularly *Fusulinella haworthi*, found by the writer in the conglomerate in several wells on the Barton arch, indicate probably lower Marmaton, although there is some possibility of Cherokee age. On the Granite ridge the unconformity occurs below shale of upper Cherokee age.

The age of the Welch conglomerate between the Granite ridge and the Barton arch is, therefore, probably upper Cherokee, but represents a progressively later overlap toward the northwest, where it is probably of early Marmaton age, and in northwestern Kansas it may be considerably younger.

Structure

Kansas has two major positive structural features. The more spectacular is the buried Nemaha Mountain range or Granite ridge,

[1] R. C. Moore, *op. cit.*

[2] John R. Reeves, "El Dorado Oil Field, Butler County, Kansas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol, 1929), p. 161.

which crosses the state trending about N. 18° E. The granite is buried under 550 feet of sediments at the north Kansas line, but plunges deeper toward the south, being about 5,500 feet below the surface at Garber, Oklahoma.

The real structural backbone of Kansas is a much larger and broader feature, the Chautauqua-Barton arch, which extends from the Ozark uplift in a northwesterly direction through Chautauqua, Barton, and Norton counties. The general trend is about N. 45° W., nearly parallel with the buried Wichita-Amarillo Mountains, which strike approximately N. 60° W. Cheney[1] suggests that the Concho Divide-Llano-Burnet positive element (Fig. 1) is similar to the Barton arch, both areas having resisted subsidence while a geosyncline developed in southern Oklahoma, where the Arbuckle and Wichita mountains were uplifted later.

Three structural depressions occur between the elevated structures, namely, the Forest City basin in the northeast, the Salina basin in the north-central, and a basin in the southwestern part of Kansas for which the name Dodge City basin is proposed.

Many smaller folds occur in Kansas and north-central Oklahoma nearly parallel with the Nemaha Mountains and crossing the Chautauqua-Barton arch, the two structural lines intersecting with angles of 100°-110° facing the Ozark Mountains. As pointed out by Fath,[2] as the sedimentary series is obviously unable to transmit horizontal stresses so far from centers of orogeny, the structural lines must indicate lines of faulting or folding in the basement rocks.

The geological history of Kansas has been very similar to that of northern Oklahoma. The same periods of erosion are evident, increasing in duration toward the northwest.

The basal sand of the sedimentary series, which is about 1,000 feet thick a few miles south of Ellsworth, must indicate a near-by pre-Cambrian topographic "high." If this was a structural elevation, it was probably in approximately the location of the Barton arch, because that area was evidently susceptible to later folding. As previously mentioned, that part of the Arbuckle limestone now found on top of the Barton arch seems to be correlated with a zone about 4,000 feet above the base of the formation in the Arbuckle Mountains, which probably

[1]M. G. Cheney, "History of the Carboniferous Sediments of the Mid-Continent Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), p. 561.

[2]A. E. Fath, "Geology of the Eldorado Oil and Gas Fields," *Kansas Geol. Survey Bull.* 7 (1921), p. 149.

indicates that the Arbuckle sea progressed gradually northward, and perhaps covered the Barton arch somewhat later than other parts of Kansas. The same conclusion was reached by White[1] in considering the southwestern part of the Ozark uplift in northeastern Oklahoma, and undoubtedly the same reasoning applies to that part of the same uplift called the Chautauqua arch in Kansas. The Barton arch and the Chautauqua arch therefore probably began their history in pre-Arbuckle time.

Following the Arbuckle there was a break in deposition, and renewal of the Barton and Ozark uplifts. It is difficult to determine how much of the Arbuckle limestone was removed at that time, and how much by post-Mississippian erosion. In Clay and Riley counties wells have shown that the Arbuckle is absent and the Simpson rests on granite. This probably is caused largely by non-deposition of the Arbuckle and indicates the existence of a pre-Cambrian positive element in northern Kansas and southern Nebraska, just west of the later uplift of the Granite ridge. The thickness of Arbuckle on the Chautauqua arch, where it is overlain by Mississippian rocks, is about 1,000 feet, but on the Barton arch, where the Mississippian is absent, it is about 250 feet. The difference may represent approximately the amount removed by post-Mississippian erosion.

The Simpson sea, like the Arbuckle, gradually transgressed northward. Only the upper part of the Simpson seems to be represented in Kansas, except in the south-central part. The Urschel limestone lies disconformably on the Simpson, and evidence of a break in deposition is not noticeable.

In Oklahoma there is a known unconformity at the outcrop between the middle Viola and the upper, or Fernvale, member. In Kansas the evidence mentioned in discussing the Urschel limestone seems to indicate that another limestone member occurs above the Fernvale, but there is a decided unconformity between this limestone and the overlying Maquoketa, because only the Fernvale is found in places in the area of the Younkin limestone inlier in Harvey County.

There is little evidence of an unconformity at the top of the Maquoketa shale. In the Seminole district the Sylvan is remarkably uniform in thickness and where it is exceptionally thin the Hunton is missing above it. In Kansas the Younkin seems to lie conformably, or perhaps disconformably, on the Maquoketa shale.

Reeds[2] has proved faunal breaks in at least two horizons in the Hunton limestone, the more important being between the Silurian and the

[1]Luther H. White, *op. cit.*, p. 10.

[2]C. A. Reeds, *Amer. Jour. Sci.*, 4th ser., Vol. 32 (1911), p. 258.

Devonian. As mentioned in discussing the stratigraphy of the Younkin limestone, this hiatus in the Forest City basin extends from the base of the Middle Devonian to Middle Silurian (Lockport). Folding at this time must have consisted of gentle warping.

Following Hunton and Younkin deposition there was a renewal of upwarping and gentle folding throughout the entire Mid-Continent region and beyond. The Ozark region, the Barton arch, the Hunton arch, on which the Seminole district is located, and the Arbuckle region were uplifted at this time. The resulting erosion truncated the pre-Mississippian rocks on the Barton arch and around the Ozarks. In the Seminole district the Hunton was removed from a considerable area, and this period of erosion is evidenced on the south side of the Arbuckle Mountains by the absence of the Hunton limestone near the town of Sylvan. On the Barton arch granite was exposed in several places, either at this time or during post-Mississippian erosion.

Another period of uplift occurred following Mississippian deposition. Further movement was recorded along the old structural lines. As explained by Levorsen,[1] there was an accompanying downwarp in southeastern Oklahoma which permitted the deposition of the Morrow group, while erosion continued on the north and west. In Kansas, west of the Nemaha Mountains and particularly over the Barton arch, this period of erosion continued from the end of Chester time until early Marmaton (middle Allegheny) time.

In the Ardmore district, Tomlinson[2] has shown that the first major uplift occurred about the end of Morrow time. In addition, as the major faunal break occurs at the top of the Morrow, it seems probable that the movement at the end of Chester time was only a broad warping and tilting of the entire Mid-Continent area toward the southeast, while the post-Morrow uplift was much more pronounced, resulting in the north-south lines of folding which generally reflect faulting of the basement rocks. This orogeny is of the utmost importance to the oil industry, for it produced many anticlinal structures which have proved exceptionally prolific oil pools.

The Nemaha Granite ridge is the best example of structures of this period. On the east side of the Augusta field, wells have proved the

[1]A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (March, 1928), p. 37.

[2]C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (March, 1929), p. 20.

existence of a fault having a downthrow of 600 feet on the east.[1] The available evidence points to the same condition on the east side of the El Dorado field.

Other structural features of this type which seem to have been formed at the same time are the Voshell, Thomas, Tonkawa, Garber, Oklahoma City, and many smaller structures in northern Oklahoma and central Kansas.

The mechanics involved in all these structures is practically the same, resulting in folding with accompanying faulting which cuts all the rocks older than Pennsylvanian. As most of them are outside the area of Morrow deposition, there is no evidence to show directly whether the faulting occurred before or after Morrow time. The deduction can be made, however, from the evidence in areas of Morrow deposition, as previously discussed.

Although it may be suspected that some movement occurred along these fault lines in the basement rocks during post-Devonian warping, the writer has been unable to find conclusive evidence of it. The Mississippian at El Dorado, where present, appears to parallel the older beds, and the thinning of the Urschel occurs in a south or southeasterly direction, regardless of position on the Granite ridge, except that it was locally removed on the higher domes. This is interpreted to mean that the thinning of the Urschel occurred on the Chautauqua arch during post-Devonian erosion, and that the Granite ridge did not exist at that time.

Renewed uplift of the Hunton arch in the Seminole district of Oklahoma is shown by erosion of the Mississippian Caney shale, which is about 400 feet thick in the Seminole City field, although only the lower 100 feet is present at Earlsboro. This uplift was not confined to the Hunton arch, however, but extended westward and was probably simply due to the southeastward tilting which began near the end of Chester time. In Oklahoma County, Oklahoma, very little Mississippian remained at the time of the faulting. In the Oklahoma City field, the vertical displacement of the Arbuckle limestone in Sec. 18, T. 11 N., R. 3 W., is approximately 2,200 feet, yet there is only 10 feet of "Mayes lime" (Chester or Osage)[2] on the downthrown block east of the fault.[3]

[1]R. L. Kidd, oral communication.

[2]Ira H. Cram, "Geology of Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull. 40-QQ* (May, 1930), pp. 36-37.

[3]Reported by Chester R. Thomas in Slick's Banta No. 1, SE.¼, SW.¼, SE.¼, Sec. 18, T. 11 N., R. 3 W., Oklahoma City field.

Taff[1] states that

> Near the beginning of the Pennsylvanian or near the close of the Mississippian, the rocks of the Arbuckle region were folded and the western part was elevated into land, probably into mountains.... Faulting on a large scale also occurred, involving the whole Paleozoic section below the top of the Mississippian, besides the pre-Cambrian granite and porphyry. After the elevation there was extensive erosion, which exposed the rock section down to the Cambrian in the western part of the Arbuckle Mountains.

The more recent data collected by Tomlinson[2] indicate that this uplift was post-Morrow rather than post-Mississippian.

The uplifts thus described resulted in the removal of all the Mississippian rocks on the crests of most of the small sharp anticlines, which must have remained exposed as islands until late Cherokee time. At Oklahoma City and Garber the basal Marmaton rests on Arbuckle. In places on the Barton arch and along the Granite ridge the granite was exposed.

Over the Barton arch the land must have been low and flat, for the products of weathering were not removed. The basal Pennsylvanian conglomerate contains residual chert, red clay, and quartz. Part of the chert is oölitic and evidently derived from the Arbuckle, though some of it may have come from the Mississippian. There are also weathered Simpson shales which would have been disintegrated if transported more than a short distance by water.

By the end of Pottsville time (early Cherokee) the Pennsylvanian sea had submerged the south end of the Granite ridge near the Oklahoma line, and had advanced northward along the east side of the ridge into Nebraska, and along the west side perhaps as far north as Wichita. Late Cherokee sediments cover the ridge at El Dorado and by early Marmaton time the sea had covered the Barton arch and nearly all the Granite ridge. The residual weathered material on the Barton arch was re-worked to some extent and became the basal Pennsylvanian conglomerate, which is the oil-producing horizon at Gorham and in practically all the small pools on the Barton arch, with the exception of the Fairport pool.

Although the Barton arch was formerly higher than the Granite ridge, it has been depressed by the post-Pennsylvanian westward tilting (Fig. 3) which extends from southwest Texas to Iowa.

[1] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," reprint of *U. S. Geol. Survey Prof. Paper 31* (1904), *Oklahoma Geol. Survey Bull. 12* (1928), p. 36.

[2] C. W. Tomlinson, *op. cit.*, p. 20.

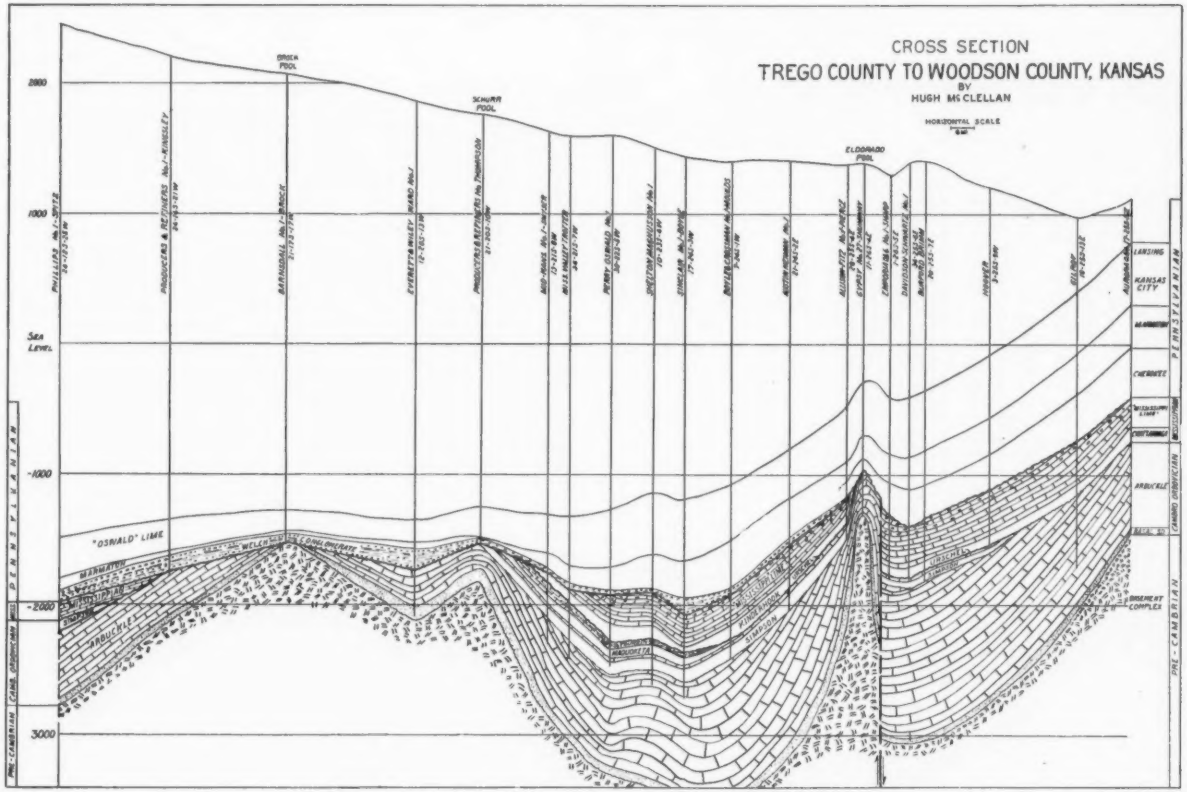

FIG. 3.—Section *AB* (Fig. 2). Vertical scale shown in feet.

CONCLUSIONS

The present distribution of the pre-Mississippian rocks in Kansas and Oklahoma is the result of a long history, which included at least three periods of major crustal warping and one period of sharper folding and faulting, with consequent erosion following each period.

Some of the broader arches began their history during the pre-Cambrian, and were repeatedly uplifted by later movements, while the smaller anticlines and faulted structures are early Pennsylvanian in age and have since been affected only by Pennsylvanian and Permian folding.

RESULTS OF ELASTIC-WAVE SURVEYS IN CALIFORNIA AND ELSEWHERE[1]

FRANK RIEBER[2]
San Francisco, California

ABSTRACT

Geophysical exploration in loosely consolidated materials presents a problem different from similar surveys in areas where there is a marked differentiation between beds. However, even in these loosely consolidated materials, velocity of wave transmission varies in general with depth of original overburden, and correlations based on this fact have been found reliable. Apparatus has been specially developed to meet the requirements of operation in such materials.

INTRODUCTION

The efficacy of seismic methods in the definition and mapping of the contact between compact lower beds and loosely consolidated overburden has been recognized for some time. It has not been so generally understood that similar procedure can also be followed for measuring the characteristics of the loosely consolidated beds, and that from such measurements structural features can be determined.

Suppose that in Figure 1 there is a competent bed of hard limestone, over which loosely consolidated sands and shales have been deposited. The mapping of the limestone and the determination of the position of the fold, if any, are relatively simple matters. A typical procedure is to place a vibration-sensitive device as at *R*, Figure 2, fire successive charges of dynamite at *S*, *S*, et cetera, in a line parallel with the strike, and obtain records of the time of travel from each source of explosion to the point of reception. It is convenient, although not essential, to plat the records of travel-time as in the graph, Figure 2. From this graph can be determined directly (1) the velocity in the upper material, corresponding with the slope of the first branch of the graph; (2) the velocity in the lower material, corresponding with the slope of the second branch of the graph; and (3) the position of the intersection of the two branches, as projected on one of the axes. These three quantities are

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, September 16, 1930.

[2]Frank Rieber, Inc., consulting engineers, 170 Second Street. Introduced by F. H. Lahee.

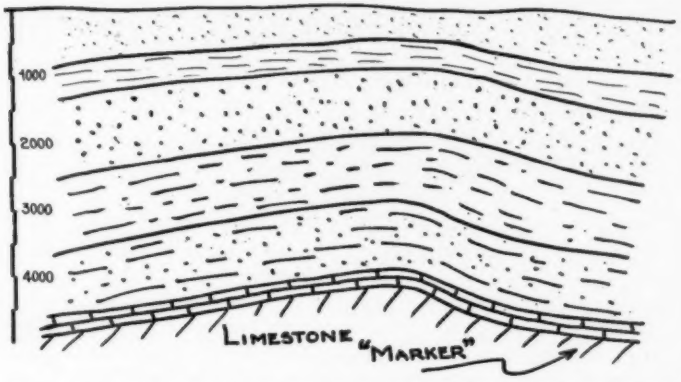

FIG. 1.—Cross section of anticlinal fold with competent bed overlain by loosely consolidated material. Depths in feet.

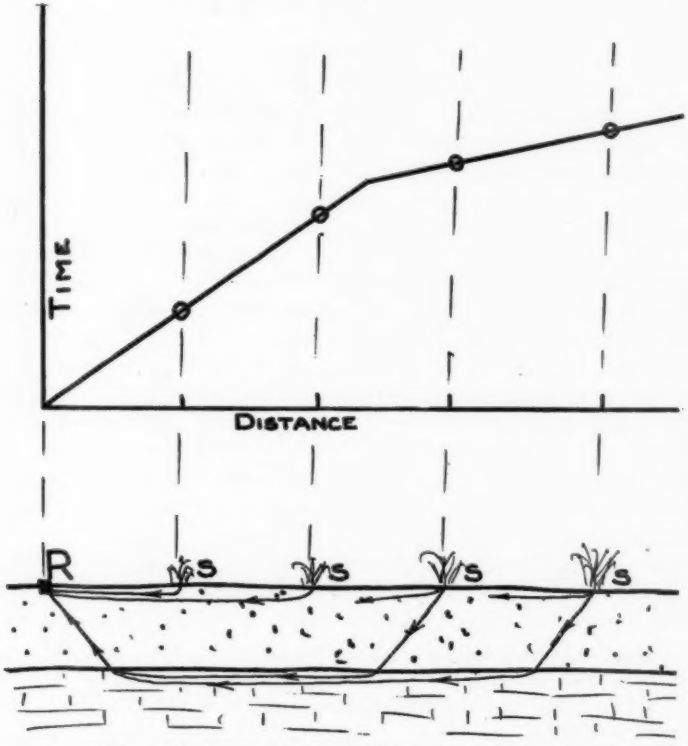

FIG. 2.—Line of shots for refraction definition of lower bed, and corresponding graph constructed from travel-times observed.

sufficient to determine the depths from the surface to the competent bed. In practice, modifications of procedure in both field and office are generally made to allow for dipping and irregular strata, et cetera. A series of determinations of depth is sufficient to define the fold.

Obviously, considerable advantage could be gained if the fold could be mapped by delineating the characteristics of the upper series of beds only. A considerable reduction in expense is effected if the mapping procedure is carried to a shallow depth only. Furthermore, and most important, a fold can be defined although no competent bed exists in the section.

It is the purpose of the writer to describe a procedure developed during the past few years, especially for use in loosely consolidated formations in California, and to give a few examples of its successful application.

RELATION OF LITHOLOGY TO VELOCITY CHARACTERISTICS

The geologist and the geophysicist approach a problem of subsurface structure from different directions, and necessarily describe it in different terms. The geologist thinks in terms of stratigraphy and lithology; the geophysicist thinks in terms of physical properties. In elastic-wave work the chief physical property considered is velocity of transmission of elastic waves. Before considering the relation between lithology and velocity of transmission of elastic waves, or transmission of stress, which is, of course, the same thing, some of the physical reasons for the variation of velocity in different substances may be considered. In general terms, velocity is a function of elasticity and density.

For such homogeneous materials as metals, the velocity of elastic waves may be computed with reasonable accuracy. The proper evaluation of the factors affecting ordinary rocks, however, presents difficulties. Both the elasticity and the density of a particular rock depend not only on the material of which the different grains are composed, but also on the material filling the voids and on the degree of contact between adjacent grains. It may, however, be conceded that a densely consolidated rock affords much more velocity than loosely consolidated overburden. In fact, this is the foundation for the ordinary method already described for mapping a competent bed, because if the velocity in the competent bed in Figure 2 were not the greater, the time-travel graph would be a straight line and no solution would be possible.

RELATION OF VELOCITY TO DEPTH OF ORIGINAL OVERBURDEN

The next question is whether differences in velocity exist in loosely consolidated material, because if such differences exist, mapping is possible, especially if a relation can be established between increases in velocity and the depth of overburden that the beds once sustained. Hedberg[1] and others have shown that increase of the pressure on sediments, such as follows increase of overburden, decreases the voids. Figure 3 shows Hedberg's results in graphic form. Compaction is thus seen to be a function of overburden once sustained.

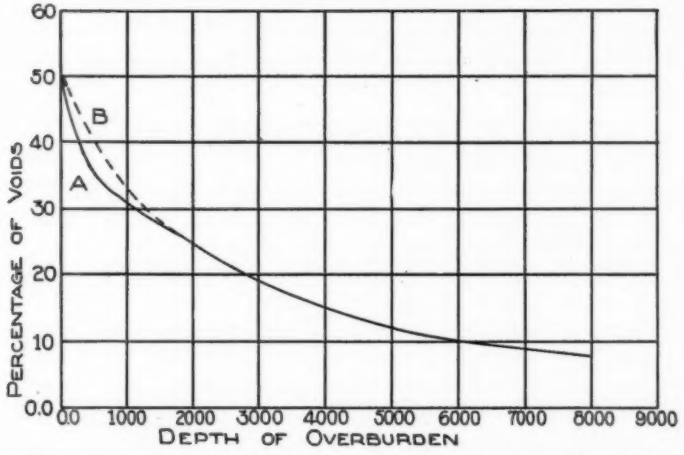

FIG. 3.—Curve showing relation of porosity to overburden. (After Hedberg.) Depths in feet.

The question of whether there is any relation between compaction and velocity is next considered. In a body of loosely consolidated sand, contact between the grains of sand is relatively imperfect. Compression applied to such sand results immediately in deforming these edges of contact, which, because of their small opposed surface, are readily compressible. Consequently, one would expect that stresses would be transmitted slowly in such material. Experimentally, the velocity in loose sand has been found to differ very little, if any, from the velocity of sound in air.

[1]H. D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (November, 1926), pp. 1035-72.

If this sand is now placed under pressure, the slight degree of contact between the sharp edges is materially increased, due partly to actual compression of the grains, and partly to the crushing of the edges of the grains and the filling of the voids with the broken material. This increase in opposed surfaces results in the material becoming less compressible, and an increase in velocity should result.

Experimentally, sands under any considerable overburden permit higher velocities than surface sands. If the various other processes tending to cement the grains together and to fill the voids are also considered, the conclusion is that a series of loosely consolidated sedimentary beds should show a steady increase in velocity with depth of original overburden. Experimentally, this is found to be true. The section shown in Figure 4 was developed near the edge of the San Joaquin Valley, California, and is typical of general conditions in that area. In lower and older beds, once subjected to higher pressures, definitely higher velocities were found than in the overlying younger beds.

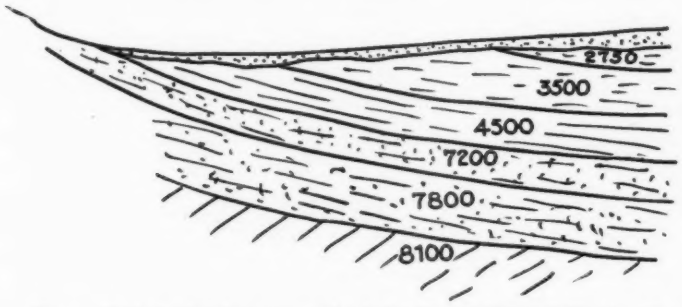

FIG. 4.—Typical subsurface cross section in San Joaquin Valley, California. Numbers indicate velocity at which waves are transmitted by beds.

If all conditions of deposition should remain absolutely uniform, velocity would, presumably, increase as a continuous function of depth of overburden. Actually, however, this occurs in few places. Sediments come from different sources, and the manner of deposition also differs. Hence, we expect velocity to be a function, not only of overburden, but of other variables as well, particularly type of material and grain structure. Nevertheless, with increase of depth of original overburden, a general tendency toward increase of velocities is to be expected, although the velocities of the successive layers may rise above or fall below the

general average trend. Experimentally this is found to be true. Examination of several areas similar to the one illustrated in Figure 4 leads to the conclusion that in the average series of sedimentary beds, the relation of velocity to depth of overburden may be expressed approximately as in Figure 5.

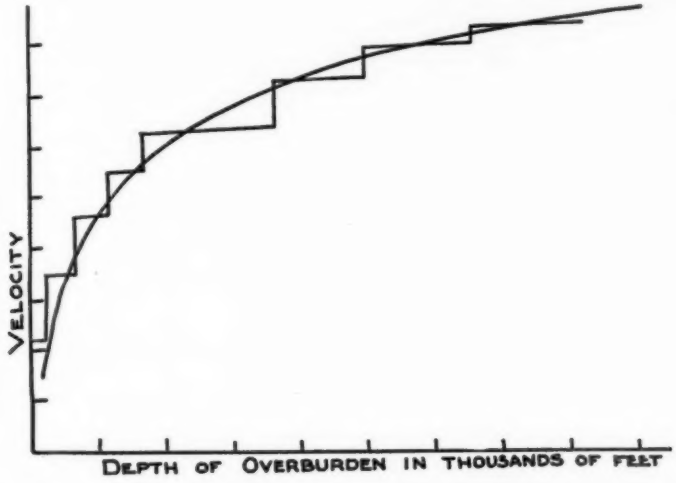

FIG. 5.—Relation of velocity to depth of overburden. The curve corresponds with a continuous increase of velocity with depth; the straight lines represent what is more likely to be found in practice, namely, a slight but sudden increase at different successive depths. Such increases may or may not correspond with lithological changes perceptible by other means of examination.

ACCURACY REQUIREMENTS IN MAPPING LOOSELY CONSOLIDATED SEDIMENTS

In mapping the contact between a high- and a low-velocity medium, a graph such as that shown in Figure 6 is obtained. A slight error in determining either branch of the graph makes little difference in the position of the intersection of the two branches; consequently, little difference in the computed depth to the contact, which, as already noted, is calculated from (1) the velocity in the lower material, (2) the velocity in the upper material, and (3) the position of the intersection of the two branches of the time-travel graph.

However, in the mapping of the contacts between successive layers of loosely consolidated materials, a different situation is found. A graph of the type shown in Figure 7 is ordinarily obtained. If the

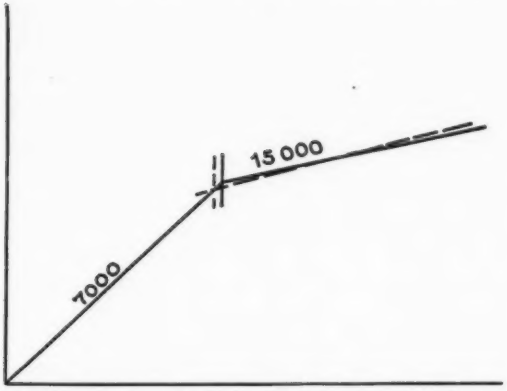

FIG. 6.—Typical time-travel graph obtained in mapping high-velocity bed. Notice that slight changes in either velocity branch would make little difference in the position of intersection of the two branches of the graph. Numbers indicate velocity in feet per second.

time readings are not accurate, an error in the determination of one or more branches of the graph may result, as shown in Figure 8, and only a slight error of this kind may make a large error in the position of the intersections; consequently, in the computed depths.

Actually, irregularities in time determinations can not be completely eliminated. For example, one shot may have to be placed in relatively

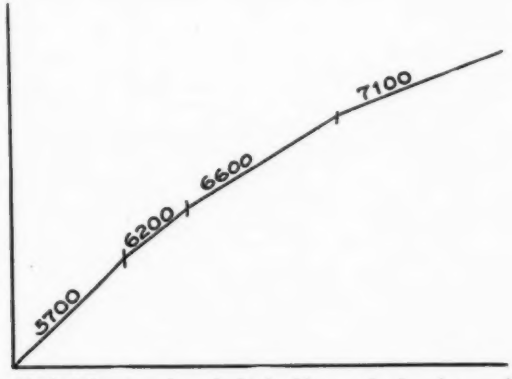

FIG. 7.—Typical time-travel graph obtained in mapping loosely consolidated beds. Numbers indicate velocity in feet per second.

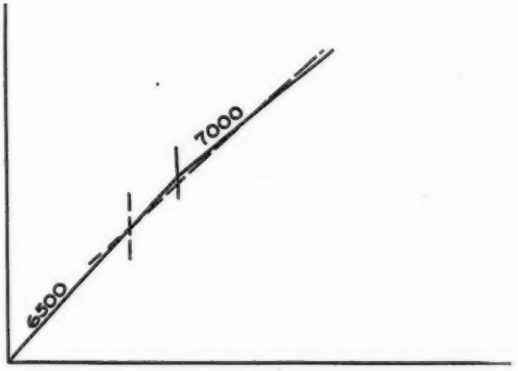

FIG. 8.—Typical graph showing effect of inaccuracy in time readings. Relatively small errors in a few readings may make a large error in the determination of the break-point; therefore, in the computed depth. Numbers indicate velocity in feet per second.

hard clay and the next in soft sand. Although this difference may extend only a few feet below the surface, a measurable difference in total time travel results. The effect of this and similar sources of error in individual observations may be minimized by comparison of results in a large area, by a system of allowances for such known but unavoidable sources of

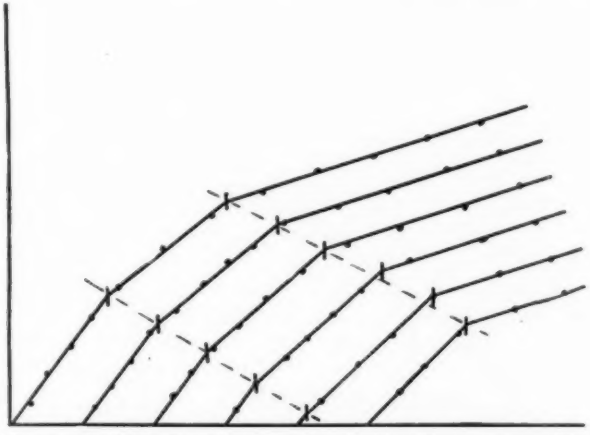

FIG. 9.—Typical series of time-travel graphs from lines on a monocline.

error as that cited, and by other methods of procedure. The necessity, however, for the maximum accuracy of instrumental work remains.

SPECIAL FEATURES OF INTERPRETATION OF RESULTS

A typical series of time-travel graphs such as might be obtained for lines parallel, or nearly parallel, with the strike on a monocline is shown in Figure 9. Notice that corresponding branches are approximately parallel. This fact assists materially in interpretation by helping to eliminate the results of unavoidable inaccuracies in time counts, et cetera.

Another common source of error is illustrated in Figures 10, 11, and 12. Figure 10 illustrates a subsurface cross section where a relatively thin bed of 6,000-foot material lies between a 5,000 and a 7,000-foot bed. If lines are shot perpendicular to the plane of the paper at the various points indicated by the broken lines, a series of time-travel graphs such as are shown in Figure 11 is obtained. Notice that the 6,000-foot bed is represented on some, but not all of the graphs. If the graphs in Figure 11 are solved directly without taking this into consideration, a cross section such as is shown by the solid lines in Figure 12 is the result. The true condition, which can be determined, or at least approximated, by a comparative study of all the graphs, is shown by the broken lines.

REQUIREMENTS FOR APPARATUS FOR MAPPING LOOSELY CONSOLIDATED MATERIALS

In general, elastic-wave apparatus for use in a sedimentary series with slight velocity changes must differ from the ordinary form of seis-

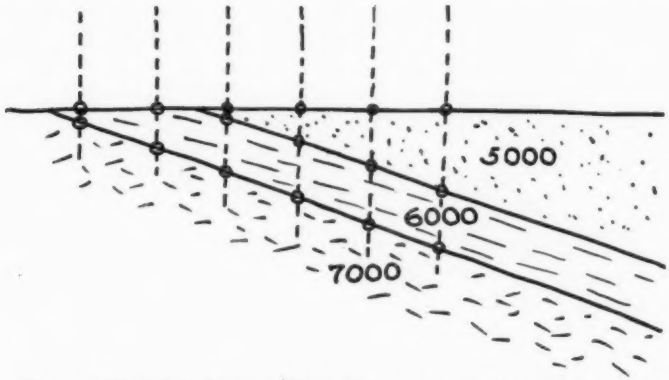

FIG. 10.—Hypothetical cross section showing relatively thin bed between strata of lower and higher velocities. Numbers indicate velocity in feet per second.

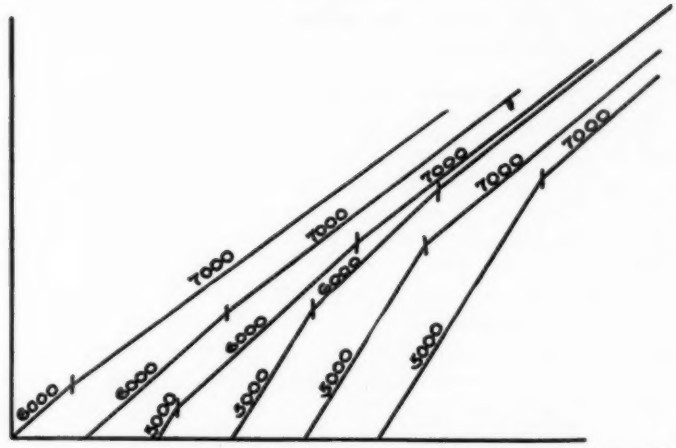

FIG. 11.—Typical time-travel graphs such as would be obtained for conditions shown in Figure 10. Numbers indicate velocity in feet per second.

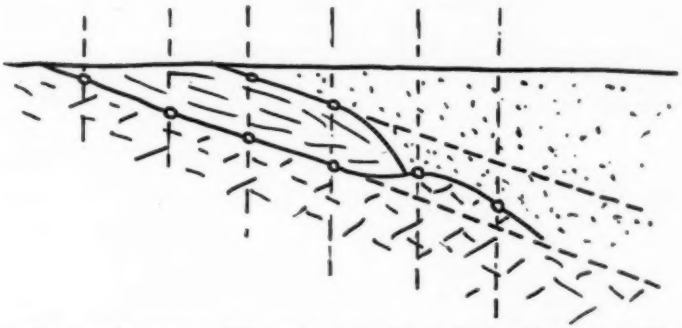

FIG. 12.—Erroneous (solid lines) and correct (broken lines) solutions for conditions of Figures 10 and 11.

mograph in two characteristics. It must be more accurate as to time, and more sensitive.

The necessity for time accuracy has been illustrated in the preceding discussion in which the effects of slight errors in time on the accuracy of the platted graph have been considered.

The necessity for sensitivity and the limit to which it can be carried may next be considered. The source of vibrations is the concussion of an explosion. The effect of the explosion can be treated as a group of vibra-

tions of widely different frequencies, sent out at the same instant. It is possible to make a receiving device that is more sensitive to some parts of this frequency range than to others.

In making this selection there are two opposing requirements. For the maximum accuracy of time the receiver must be made responsive to the high frequencies; for economy of dynamite, the low frequencies must be favored. A desirable compromise for general conditions in California requires the maximum sensitivity at approximately 100 cycles per second.

When an elastic wave passes from bed to bed, only part of the wave is refracted in such a manner that it can eventually return to the surface and reach a receiving device. Where there is a series of such refractions, caused by a succession of beds of increasing velocity, the relative intensity of the wave traveling to the deepest bed to be mapped becomes very small. The mapping of the bed, however, must be based on the travel time of this wave for those records where this wave is the first to reach the receiver. If the intensity of the wave becomes too small, its arrival time can not be determined accurately, and the bed can not be mapped. Attempts to obviate this difficulty can be made along one or both of two lines. The sensitivity of the receiver can be increased, or the amount of dynamite can be increased.

There is a practical limit to the extent to which the first course, namely, increasing the sensitivity of the receiver, may be carried. Local earth "unrest" includes the slight natural vibrations due to wind, earth tides, temperature and barometric changes, slight movements along active faults, local highway traffic, et cetera. Any receiving device may, by an increase of amplification, be rendered sufficiently sensitive so that vibrations from such sources are recorded. When such a degree of sensitivity has been attained, it is obvious that if one wishes to receive and record a vibration from dynamite, and to recognize it distinctly as compared with the local unrest vibrations, the dynamite wave must be definitely stronger than any accidental local wave. In other words, if the sensitivity is such that local accidental unrest begins to be recorded, further increase in sensitivity is useless because such increase merely magnifies the explosion wave and the unrest in the same proportions. In such a condition, the legibility of the records is improved only by using more dynamite.

The foregoing facts have been presented in order to explain a common misunderstanding, namely, that it is possible by some special procedure of amplification to offset or avoid this $\frac{\text{unrest}}{\text{signal}}$ ratio.

A few examples of results are submitted. Figure 13 is an example of mapping where considerable contrast existed between the recorded ve-

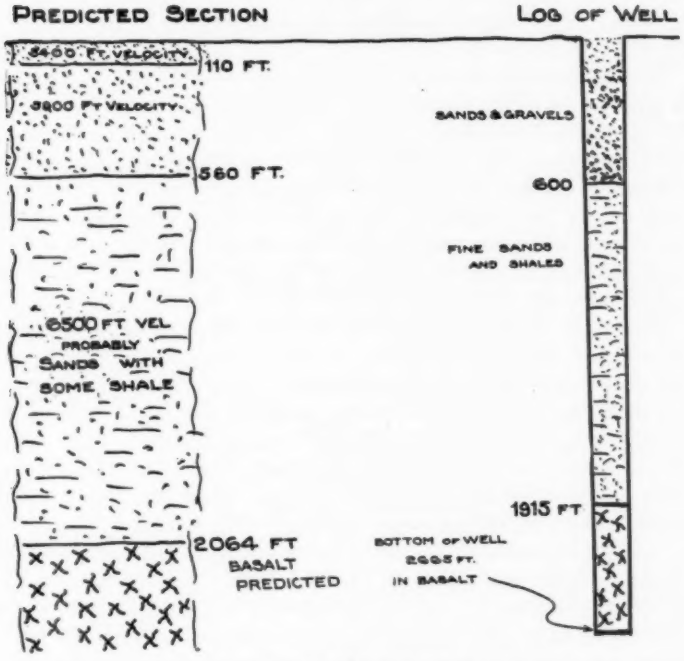

FIG. 13.—Predicted cross section and log of well drilled a year later.

locities. Although the area surveyed was a flat plain, the regional geology indicated that either igneous intrusions or anticlinal structures which might favor the accumulation of oil might exist somewhere under the plain. A gravity survey showed an anomaly that might be explained by either of the foregoing hypotheses. A magnetic survey showed an anomaly which could be explained best by the intrusion theory but which was not entirely inconsistent with the assumption of an anticline.

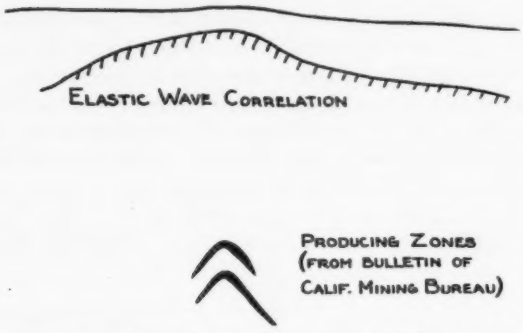

FIG. 14.—Cross section across Lost Hills field, California.

An elastic-wave survey was then made. At a computed depth of approximately 2,000 feet from the surface, a bed affording a velocity higher than unaltered sediments was found. The velocity was found to be essentially the same as that of basalt outcrops in the adjacent hills. A further check was obtained when a bed permitting the same velocity

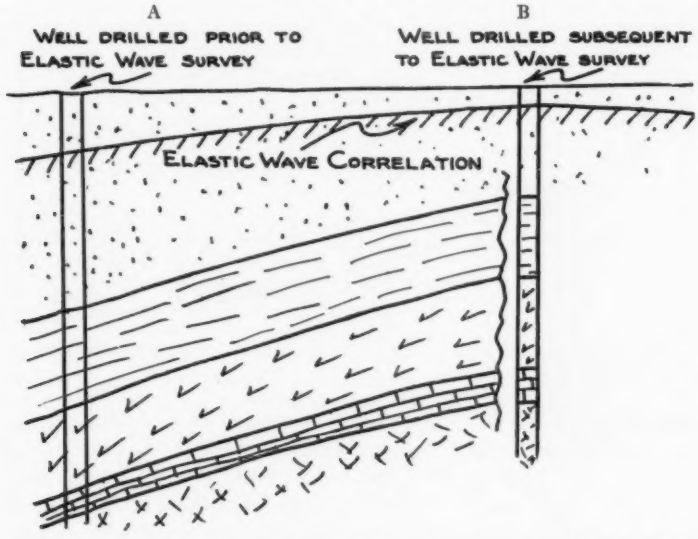

FIG. 15.—Predicted cross section from elastic-wave survey and actual log of well.

was found in an adjacent area at a computed depth agreeing closely with the depth to basalt in a well drilled in that area. It was predicted that the cause of the anomalies shown in the other surveys would be found to be a mass of basalt at a depth of approximately 2,000 feet, the predicted cross section being shown in Figure 13. A final test of the accuracy of the elastic-wave work was obtained a year later when a well, the log of which is also reproduced, was drilled more than 700 feet into the basalt.

Among determinations in loosely consolidated strata, Figure 14 shows a profile developed across the axis of the Lost Hills field, near

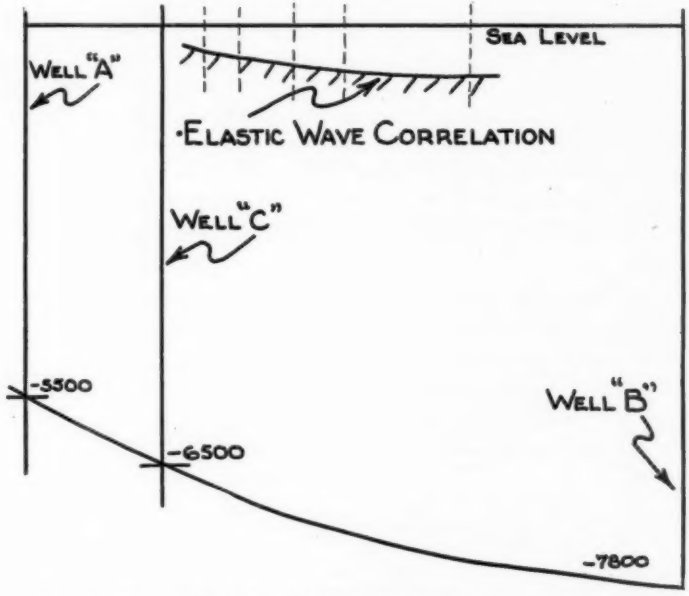

FIG. 16.—Cross section in Los Angeles basin. Numbers indicate velocity of waves in beds in feet per second.

Bakersfield, California. The general conformity between the elastic-wave determination and the producing sands is evident.

Well *A* in Figure 15 was drilled several years ago. From an elastic-wave survey made later, it was predicted that certain geological horizons cored in well *A* would be encountered in the vicinity of well *B* at approximately the depths indicated. Comparison with the log of well *B*,

drilled several months later, shows a close agreement between the predicted and the actual depths.

In Figure 16 is a cross section developed from three wells drilled in the vicinity of a producing field in the Los Angeles basin. The lower horizon shown is productive in the field itself. The upper line was determined by an elastic-wave survey made chiefly in the hope of finding evidence of structure between wells *B* and *C*. As would be expected, the upper bed seems to have a smaller dip than the lower, but the evidences of essential conformity are definite.

DISCUSSION

DONALD C. BARTON, Houston, Texas: Geologically-geographically, the so-called "inclined" path might be expected in seismic prospecting rather than the "vertical" path advocated by certain geophysicists. Their argument is based on the assumption of homogeneous strata, an assumption which, geologically, is not justified. Any geologist who has studied formations in the field knows that really homogeneous strata are practically non-existent. At least faint variations occur in short distances both horizontally and vertically. In addition to the initial depositional irregularities there are everywhere many small secondary irregularities: faint warping of the strata, faint squeezing, local cementation, differential curvature, faulting, et cetera. Such a formation as the Austin chalk may be thought of somewhat casually in the office as a distinctly homogeneous formation, but a brief examination of good exposures in the field quickly reveals many irregularities. If beds are not homogeneous and if these many irregularities of various sizes are present, confused diffraction and refraction occur, and the path of fastest time is easily shown mathematically to be that used in the "inclined-path method," that is, the angle of incidence is arc $\sin\frac{V_1}{V_2}$ where V_1 is the velocity of the relatively low-speed upper bed and V_2 is the greater speed in the underlying bed. This angle is, of course, the same as the critical angle which would be obtained if the wave path followed the law of refraction of light. The energy coming in on the fastest time path may be extremely faint compared with that coming in on the other path, but, theoretically, the first wave should come in on that time path and be detectible if sufficient energy is put into the explosion and if sufficiently sensitive instruments are used to detect the incoming waves. But, as Mr. Rieber has mentioned, it is to be expected that the faint waves coming in on the path of fastest time may be missed if the ratio of the size of the explosion charge to the effective sensitivity of the instrument under the conditions used is not large enough.

RESEARCH NOTES

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The purpose of the research committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the research committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

PETROGRAPHIC STUDY OF SALT-DOME CAP ROCK

A petrographic study of salt-dome cap rock was sponsored last summer by the Freeport Sulphur Company in the hope of getting information about the origin and conditions of formation of the sulphur deposits. L. S. Brown, adjunct professor of geology at the University of Texas, spent the summer at Bryan Heights studying the company's suites of cores and samples from the Bryan Heights and Hoskins Mound domes, Brazoria County, Texas.

A report on his study will be published presently. His conclusions are here stated briefly.

1. The limestone cap is an alteration product of the gypsum-anhydrite cap.
2. Alteration is not an effect of reaction of hydrocarbons and the gypsum-anhydrite.
3. The anhydrite is primary.
4. The anhydrite contains inclusions of primary sulphur.

5. The sulphur replacing anhydrite is in part, at least, a residual accumulation of the primary sulphur in the anhydrite, and a considerable part was deposited contemporaneously with the calcite of the limestone cap.

6. The anhydrite is schistose throughout; the common bandings dipping at an angle of about 45° are pressure shearing planes at an angle of about 45° to the direction of the pressure of upthrust.

Final conclusions were not reached in regard to the paragenesis of the sulphur of the commercial deposits.

The study was devoted almost wholly to material from Bryan Heights and Hoskins Mound. During the coming academic year, Professor Brown is broadening his study to cover the cap rock of the interior domes of Texas and Louisiana and the relation of the salt-dome anhydrite to the other anhydrites of Texas and Louisiana. Professor Brown would like very much to obtain anhydrite from any southern or southwestern locality and from any known horizon, particularly of Comanche or Permian age. Drill cuttings are usable, but cores or fragments of cores are much more satisfactory. Samples should be sent to Professor L. S. Brown, University Station, Austin, Texas.

DONALD C. BARTON

HOUSTON, TEXAS
October, 1930

REVIEWS AND NEW PUBLICATIONS

"Geology of the Arkansas Paleozoic Area with Especial Reference to Oil and Gas Possibilities." By CAREY CRONEIS. *Arkansas Geol. Survey Bull. 3* (Little Rock, 1930). 457 pp., 45 plates, 30 figures, 6 tables. Price, including mailing charges, $3.20.

Since the discovery, in the year 1925, of the Clarksville gas field, near Clarksville, Johnson County, Arkansas, there has been a revival of interest in the Arkansas Valley as a gas-producing area. The report on the "Geology of the Arkansas Paleozoic Area" by Carey Croneis, recently published, was prepared chiefly because of this discovery and is intended as a guide to further prospecting, not only in the Arkansas Valley but thoughout the whole Paleozoic area of Arkansas.

As is customary in reports of this kind, the first few pages are devoted to the introduction and to the subject of physiography. The former discusses the need for such a report; the latter discusses the geologic setting of the several subdivisions of the area. Of special interest in this discussion is the classification of the Ouachita Mountains and the Arkansas Valley in a single Ouachita physiographic province, thus bringing the Ouachita Physiographic Province into juxtaposition with the Ozark Plateaus Province. This is a departure from the ruling of the United States Geological Survey which places the Ouachita Mountains and the Arkansas Valley in separate provinces, but the change is amply justified, inasmuch as more of the details of the structure and stratigraphy in the two areas are now known.

The second part of the report is devoted to the stratigraphy of the region, discussed in two sections, (1) the Ozark Highlands section, and (2) the combined Arkansas Valley and Ouachita Mountain section. A good general description and correlation of each formation are given, with notes in regard to the petrolific significance of each. Where fossils occur, faunal lists are given, and plates of characteristic fossils, excellently photographed, accompany many of the descriptions of formations.

The third part consists of a chapter on the igneous rocks of central Arkansas, by the author assisted by Marland Billings, in which the main facts of the igneous activity in this region are reviewed and in which some recently discovered dikes are described.

The fourth part of the report discusses the origin and nature of the structure of this entire area in considerable detail. All the important anticlines, synclines, and faults have been named and are shown on a map. Each is described, its precise location, its structural details, and its prospective value from the point of view of oil and gas being mentioned. If any wells have been drilled on any of these structures, they are discussed and their logs are included. The reconnaissance mapping of the numerous structures in the Arkansas Valley and Boston Mountains is the chief contribution made in this publication.

In the fifth and last part of the report, the author describes separately each of the nine gas-producing areas in the Arkansas Valley, giving complete information, in so far as this is possible, for each field. He concludes from his study: (1) that the Arkansas Valley area may be expected to produce gas in all parts where structural conditions are favorable, but that the southern border is perhaps somewhat less promising than the other parts; (2) that the Boston Mountains, in certain limited areas where the structural conditions are favorable, may produce gas and some oil; (3) that the Springfield Plateau offers some promise of both oil and gas, particularly in areas near its southern boundary; and (4) that the Salem Plateau, the Athens Plateau, and the Ouachita Mountains have almost no prospective value and should not be drilled for oil and gas.

The entire report is excellently written, very readable, covers the subject completely, yet is not too long, and is in every respect an admirable piece of work, reflecting credit on the author, the publishers, and the Survey.

C. W. HONESS

TULSA, OKLAHOMA
October 20, 1930

RECENT PUBLICATIONS

ARKANSAS

Topographic Map of the Gulf Coastal Plain of Arkansas, Showing Highways and Oil and Gas Fields (Arkansas Geological Survey with the coöperation of the U. S. Geol. Survey and the Arkansas State Highway Commission, Little Rock, Arkansas, 1930). Scale, 1:500,000. Contour interval, 100 feet. Paper, three colors. Size, 32 × 36½ inches.

Topographic Map of the State of Arkansas. Same publishers as preceding map. Shows highways, mineral industries, power-transmission lines, and oil and gas pipe lines. Scale, 1:500,000. Contour interval, 250 feet. Paper, three colors. Size, 32 × 36½ inches.

AUSTRIA

"Zur Geologie des ersten Erdölfundes in Niederösterreich," by Karl Freidl. *Petrol. Zeits.* (Vienna, Austria, October 1, 1930), pp. 987-92, 1 illus.

CALIFORNIA

"Gas-Lift Method of Flowing Oil Wells (California Practice)," by H. C. Miller. *U. S. Bur. Mines Bull. 323* (Supt. Documents, Washington, D. C., 1930). 118 pp., 45 illus. Price, $0.30.

Map of Elk Hills Naval Petroleum Reserve. (U. S. Geological Survey, Washington, D. C., 1930.) Scale, ½ inch equals 1 mile; contour interval, 20 feet. Price, $0.10.

COLORADO

Base Map of Colorado. (U. S. Geological Survey, Washington, D. C., 1930.) Printed in 2 colors; dimensions, approximately 41 × 54 inches; scale, 1 inch equals 8 miles. Price, $0.25.

GENERAL

"Isostatic Compensation in Relation to Geological Problems," by George R. Putnam. *Jour. Geol.*, Vol. 37, No. 7 (Chicago, Illinois, October-November, 1930), pp. 590-99, 1 fig.

Sons of the Earth—The Geologist's View of History, by Kirtley F. Mather. (W. H. Norton and Company, Inc., 70 Fifth Avenue, New York, New York, 1930.) 272 pp., 8 pls., 83 illus. Cloth. Price, $3.50.

"Distribution of the Pre-Mississippian," by Hugh McClellan. *Oil and Gas Jour.* (Tulsa, Oklahoma, October 23, 1930), pp. 32, 33, 107-9, 3 illus.

"Recovery of Oil from Sands by the 'Gas-Drive,'" by Joseph Chalmers, I. H. Nelson, and D. B. Taliaferro. *U. S. Bur. Mines Report of Investigations 3035* (Section of Publications, U. S. Bur. Mines, Washington, D. C.). 12 pp., 6 illus. Free.

"Some Properties of Limestone as a Reservoir Rock," by W. V. Howard and W. W. Love. *Econ. Geol.*, Vol. 25, No. 7 (Lancaster, Pennsylvania, November, 1930), pp. 720-36, 2 figs.

"An Examination of Clays Associated with Oil-Bearing Strata in the United States," by E. McKenzie Taylor. *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 84 (London, October, 1930), pp. 681-83.

Limestones, Their Origins, Distributions and Uses, by F. J. North. A profusely illustrated geological and industrial history of limestone in text-book form. (Thomas Murby and Company, London; D. Van Nostrand Company, New York, 1930.) 467 pp., frontispiece and 236 figs. Cloth. Price, 16 s., net.

GEOPHYSICS

"Sur les prospections électriques du pétrole," by M. A. Belluigi. *La Revue Pétrolifère* (Paris, October 18, 1930), pp. 1451, 1453.

INDIA

"Oil Occurrences in the North-West Punjab," by G. Benson-Cooke. *Petrol. Times* (London, October 18, 1930), pp. 613-15, 2 illus.

KANSAS

The Kansas Geological Survey, Lawrence, Kansas, announces the following publications.

"The Geology of Cloud and Republic Counties, Kansas," by Monta E. Wing. *Bull. 15.* Mailing charges, $0.20.

"The Geology of Mitchell and Osborne Counties, Kansas," by Kenneth K. Landes. *Bull. 16.* Mailing charges, $0.20.

The Kansas Geological Survey also announces that a few copies of *Bulletin 1* ("Special Report on Well Waters"), hitherto reserved for library sets, are now available for general distribution. Mailing charges, $0.20.

KENTUCKY

"Natural Gas Sands of Eastern Kentucky," by W. R. Jillson. Correlation chart based on actual records for every important gas field. Correlation datum: top of Devonian Black shale and base of Mississippian "Big lime."

Kentucky Geol. Survey Pub. (Frankfort, 1930). Single sheet. Size, 25 × 30 inches.

"Directory of Kentucky Mineral Operators," by Wilbur Greeley Burroughs. Includes oil and gas producers, pipe lines, and refineries. *Kentucky Geol. Survey Pub.*, Ser. 6, Vol. 32 (1930). 186 pp. Cloth.

"Devonian Rocks of Kentucky," by Thomas Edmund Savage *et al.* Includes "The Geology of the Midland Trail in Kentucky," by Armin Kohl Lobeck. *Kentucky Geol. Survey Pub.*, Ser. 6, Vol. 33 (1930). 257 pp., 4 pls., 77 figs. Cloth.

MONTANA

"Preliminary Structure-Contour Map of the Bears Den, Flat Coulee, and Whitlash Districts, in North-Central Montana." *U. S. Geol. Survey Pub.* (Washington, D. C., 1930). Based on field investigations by C. E. Erdmann, in 1929, supplemental to reconnaissance investigations by A. J. Collier, in 1923. Maps obtainable from U. S. Geol. Survey, Washington, D. C.; 315 Fratt Building, Billings, Montana; Shelby, Montana. Free.

NEW YORK

"Geology of Gas Fields of New York," by Paul D. Torrey. *Oil and Gas Jour.* (Tulsa, Oklahoma, October 30, 1930), pp. 67-70, 107.

POLAND

"Analizy Solanek z Niektorych Otworów Schodnicy i Urycza (Analyses of Salt Waters of Some Wells in Schnodnica and Urycz)," by Karol Katz. *Geol. Survey of Poland Carpathian Station Bull. 20* (Lwow, Poland, 1930). In Polish and French. 15 pp.

"Nowy Atlas Geologiczny Boryslawia (New Geologic Atlas of Boryslaw)," by K. Tolwinski and collaborators. "Explanatory Text with Detailed List of Wells in Region of Boryslaw," by St. Krajewski and E. de Vassart de 'Hozier. *Geol. Survey of Poland Carpathian Station Bull. 19* (Lwow, Poland, 1930). In Polish and French. 5 colored plates of longitudinal and transverse geologic sections on scale of 1:10,000. Size, 27 × 34 inches. Text, 15 pp., list of wells, 30 pp. Price, Zloty 50 ($5.63). Parts of this bulletin published in 1929 were (1) structural map on scale of 1:5,000 and (2) production map on scale of 1:10,000.

TEXAS

Tentative Correlation of the Named Geologic Units of Texas, compiled by M. Grace Wilmarth, secretary of Committee on Geologic Names. (U. S. Geol. Survey, Washington, D. C., September 1, 1930.) 3 charts, each 23½ × 29½ inches.

The Bureau of Economic Geology, Austin, Texas, announces the following publications during 1930.

"Mineral Resources of Travis County," by E. H. Sellards. Price, $0.25.

"Contributions to Geology, 1930." Contains (a) "Subsidence in Gulf Coastal Plains Salt Domes," by E. H. Sellards; (b) "The Stratigraphy of the Trinity Division as Exhibited in Parker County, Texas," by Gayle Scott;

(c) "Ripple Marks of Large Size in the Fredericksburg Rocks West of Fort Worth, Texas," by Gayle Scott; (d) "A Preliminary Report on the Geology of Montague County, Texas," by Fred M. Bullard and R. H. Cuyler; (e) "New Rudistids from the Texas and Mexican Cretaceous," by W. S. Adkins; (f) "Texas Comanchean Echinoids of the Genus Macraster," by W. S. Adkins; (g) "Correlation of Five Oil Wells in North Central Texas," by H. L. Johnson; (h) "Producing Horizons in the Big Lake Oil Field, Reagan County, Texas," by E. H. Sellards. *Bull. 3001.* Paper cover, $1.00; cloth bound, $1.75.

"Geology of Bell County," by W. S. Adkins and M. B. Arick. *Bull. 3016.* 92 pp., map. Price, $1.00.

"Calcareous Foraminifera in the Brownwood Shale Near Bridgeport, Texas," by Helen Jeanne Plummer; and "Foraminifera of the Cisco Group in Texas," by Joseph A. Cushman and James A. Waters. *Bull. 3019.* 90 pp., 12 pls. Price, $1.00.

"Geology of Stonewall County," by L. T. Patton. *Bull. 3027.* Price, $0.50.

"Geology of the Glass Mountains." Part 1, "Descriptive Geology," by P. B. King. Quarto. (In press.) *Bull. 3038.* Price, $2.50.

THE ASSOCIATION LIBRARY

Headquarters acknowledges the following library accessions.

CANADA

From R. B. Harkness:

Geological Survey of Canada Report of Progress from Its Commencement to 1863; Illustrated by 498 Wood Cuts in the Text and Accompanied by an Atlas of Maps and Sections, by William E. Logan. 983 pp.

Geological Survey of Canada Report of Progress from 1863 to 1866, by William E. Logan and others. 321 pp.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852. Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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R. Clare Coffin, John G. Bartram, Frank E. Lewis

SAN ANTONIO MEETING, MARCH 19-21, 1931

Active steps are being taken toward formulating the technical program for our annual meeting next March in San Antonio, Texas. Among major topics which will receive attention are the following.

1. Geological and petroleum development in South Texas and adjoining parts of Mexico
2. Geological and petroleum development in the West Texas salt basin
3. Occurrence of oil in igneous rocks and in pre-Cambrian rocks
4. Origin of oil

Several papers are expected under each of these headings.

Among the papers submitted under heading 4, we are promised an instructive contribution by Benjamin T. Brooks on "Chemical Evidences Bearing on the Theories of Petroleum Origin."

As chairman of the research committee, Alex W. McCoy has been developing plans for Volume III of *Structure of Typical American Oil Fields*. Very interesting papers have been promised for this volume on such subjects as the following.

1. Relation of unconformities to oil migration
2. Analysis of information relative to carbon ratios
3. Problems bearing on porosity, cementation, and compaction
4. Natural history of petroleum in response to environment
5. Oil-field waters

It is hoped that many of these papers will be ready for presentation and discussion next March.

The Division of Paleontology and Mineralogy is preparing a program as usual.

Through the efforts of R. B. Whitehead, the leading airplane mapping concerns in the Mid-Continent region and in California have agreed to coöperate in preparing a comprehensive talk, illustrated by moving pictures, on the making of airplane maps.

We are most fortunate in having arranged for Laurence M. Gould, geologist and second-in-command of the Byrd South Polar Expedition, to deliver the popular lecture on the evening of March 19.

The personnel of our program committee, as at present constituted, is as follows.

MAIN PROGRAM COMMITTEE

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K. C. Heald, regional associate editor—general papers
W. A. Thomas, regional associate editor—Appalachian region
Frank C. Greene, regional associate editor—north Mid-Continent
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Donald C. Barton, regional associate editor—Gulf Coast
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SUB-COMMITTEE FOR WEST TEXAS SALT BASIN

R. E. Rettger, *chairman*	R. L. Cannon	John E. Adams

Donald C. Barton, president of the Society of Petroleum Geophysicists, has appointed the following committee on geophysical papers.

GEOPHYSICAL PAPERS

G. H. Westby, *chairman*	H. A. Aurand	George M. Bevier
D. M. Collingwood	O. C. Lester, Jr.	Paul B. Whitney

FREDERIC H. LAHEE

SUGGESTIONS TO AUTHORS

Members are now writing their manuscripts for the Sixteenth Annual Meeting, which will be held at San Antonio, March 19-21, 1931. On pages 1582-83 of this *Bulletin* is a preliminary statement about the technical program. In order to facilitate preparation of the program for satisfactory presentation of all papers, members should submit subjects and abstracts of their papers early in January. Frederic H. Lahee, third vice-president in charge of editorial work, is general chairman of the technical program committee. His address is Box 2880, Dallas, Texas. Delay in forwarding information about manuscripts may prevent inclusion in the printed program. Such preliminary information should include: subject of paper; name of author as it is to be printed; company or business connection (as chief geologist, petroleum engineer, vice-president) and address; probable length of paper in double-spaced typewritten pages; number of lantern slides or chart displays; number of minutes required for oral delivery; date manuscript will be ready and sent to chairman.

Manuscripts presented on the programs of the Association are the property of the Association to be published at the discretion and under the supervision of the executive committee. They are not to be published elsewhere than in the copyrighted publications of the Association unless special arrangement is made with the business manager of the Association and special permission is granted for such outside publication. Authors who desire to publish program papers elsewhere, or who are requested to send copies of their papers to be published elsewhere, should get permission from Association headquarters, Box 1852, Tulsa, Oklahoma.

It is *Bulletin* policy to publish only original scientific contributions. It is generally preferable to publish Association papers originally in the *Bulletin*. If advance publication is desired, for some special reason, previous to *Bulletin* publication, the author should send to headquarters an extra copy of the manuscript, both text and illustrations, with the name of the particular journal in which such publication is desired. This procedure secures recognition of Association origin, *Bulletin* priority, and editorial scrutiny.

Abstracts may be submitted as late as February 20 for inclusion in the printed program for the San Antonio Meeting. As no preprints of papers will be made for the meeting this year, authors are requested to submit three carbon copies of their manuscripts with the first copy in order to facilitate disscussion in advance of the meeting. Manuscripts thus submitted in advance should be in Dr. Lahee's hands by February 15.

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AT HOME AND ABROAD

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with headquarters especially concerning positions available to active and associate members.

SILAS L. GILLAN, mining engineer and geologist, was recently elected president of the Engineers' Club, 833 South Spring Street, Los Angeles, California. Other officers are HARRY L. CALDWELL, vice-president, THURSTON H. ROSS, vice-president, and LEROY C. WILLIAMS, secretary-treasurer. Local meetings of the Pacific Section of the Association are held at the Club. Mr. Gillan announces that guest cards are available for Association members visiting in Los Angeles.

The Oklahoma Academy of Science held its fall meeting at the University of Tulsa on November 28 and 29, 1930. A. N. MURRAY, of the department of geology, University of Tulsa, is vice-president, Section B, Geology.

BASIL V. ZAVOICO, consulting geologist and petroleum engineer of Tulsa, Oklahoma, is the author of an article on "Motor Fuel-Distributing Pipe Lines," in the October issue of *World Petroleum*.

DAVID DONOGHUE, of Fort Worth, Texas, technical advisor, Central Proration Committee of Texas, has an article in the October 23 issue of the *Oil and Gas Journal*, entitled "Difficulties in Proration in Texas Explained by Technical Advisor." This paper was presented before the Petroleum Division of the A. I. M. E. at the Tulsa meeting, October 2 and 3.

J. S. IVY, head of the geological department of the Louisiana Gas and Fuel Company and associated companies at Shreveport, Louisiana, for several years, has been sent to Roumania by the United Gas Company, with which the Louisiana Gas and Fuel Company was recently merged.

WILLIAM W. COPP, petroleum engineer and geologist, died on October 20, 1930, in San Fernando, California.

HEWLETT A. RUSSELL, formerly with the Indian Territory Illuminating Oil Company in West Texas, has opened an office, as consulting geologist, in San Antonio, Texas.

RALPH E. GRIM, formerly assistant state geologist of Mississippi, is now connected with the department of geology at The State University of Iowa, Iowa City, Iowa.

DOUGLAS FYFE, 215 West Seventh Street, Los Angeles, California, was in Peru last summer.

E. C. TEMPLETON, formerly with the Union Oil Company in Venezuela, is now working for the same company in Los Angeles, California.

ROBERT B. MORAN, 215 West Seventh Street, Los Angeles, California, recently went to Peru.

G. E. LASKEY, formerly with the Shell Corporation at Wichita Falls, Texas, is now with the United Gas Corporation subsidiary, the Northern Texas Utilities, at the same place.

FRANCIS GLOSTER FORMAN is assistant geologist for the Geological Survey of Western Australia at Perth, W. A. Recent exploration in the West Kimberly division has resulted in good showings of oil and gas at a depth of 3,100 feet on a dome at Poole Range.

LAWRENCE WILLIS CLARK and DOROTHEA JULIA SOLAR were married on October 18, 1930, at Cincinnati, Ohio. Mr. Clark has offices at 1736 Milam Building, San Antonio, Texas.

F. A. MELTON, of the University of Oklahoma, Norman, Oklahoma, gave a talk before the Tulsa Geological Society, at its meeting, October 20, 1930, on the subject of "Recent Joint Studies in the Southwest and Their Bearing on Tectonic History." At the November 3 meeting, JAMES I. DANIELS, Continental Oil Company, Ponca City, Oklahoma, presented a paper on "Pre-Pennsylvanian Unconformities in Central Kansas."

The Houston Geological Society held its annual business meeting for the purpose of electing officers, on October 7, 1930. The officers are as follows: president, J. BRIAN EBY, Shell Petroleum Corporation; vice-president, ALVA CHRISTINE ELLISOR, Humble Oil and Refining Company; secretary-treasurer, JOHN F. WEINZIERL, consulting geologist and geophysicist, Petroleum Building.

MARTIN VAN COUVERING, petroleum engineer, 704 Wright and Callender Building, Los Angeles, California, has an article entitled "So This Is Venice!" in the November issue of the *Oil Bulletin*.

OLAF P. JENKINS, chief geologist, California State Division of Mines, San Francisco, California, has an article in the November number of the *Oil Bulletin*, entitled "Geological Survey of California Under Way." Mr. Jenkins is co-author with WALTER W. BRADLEY, state mineralogist, California State Division of Mines, of an article entitled "A Geological Survey of California," which appears in the November issue of *Mining and Metallurgy*. Both papers list the twelve field projects sponsored by the Geologic Branch, State Division of Mines.

CAREY CRONEIS, Walker Museum, University of Chicago, Chicago, Illinois, has an article on "A New Type of Paleontologic Table" in the November issue of the *American Journal of Science*.

W. F. EASTMAN has returned from Java after three years spent in Arabia and the Dutch East Indies. His address is 9 Locust Avenue, Danbury, Connecticut.

W. G. WOOLNOUGH, government geologist for Australia, has returned to Canberra, after an extensive trip through the United States and Argentina.

T. K. HARNSBERGER, of the Shell Petroleum Corporation, has returned to Tulsa after spending several months in Germany recuperating from a prolonged illness.

JOHN L. RICH, consulting geologist, Ottawa, Kansas, has been working in New York state.

H. C. VANDERPOOL has resigned from the Rycade Oil Corporation of Houston, Texas.

T. S. COX, formerly of the geological department of the Phillips Petroleum Company at San Angelo, Texas, has opened offices as a consulting geologist, at Beeville, Texas, and will specialize in southwest Texas territory.

F. C. SEALEY, Houston, Texas, is chairman of the Darst Creek advisory committee, dealing with prorating activities in the Luling fault zone field of that name. Mr. Sealey is assistant division manager of The Texas Company in the South Texas territory.

E. R. LILLEY, department of geology, New York University, New York City, who was awarded the research fellowship of the Guggenheim Foundation, will be in England for several months to study mining conditions in general. Mr. Lilley delivered an address before the Oil Industries Club, London, on October 31.

BELA HUBBARD, formerly of the Creole Petroleum Corporation, Maracaibo, Venezuela, is now employed by the Carter Oil Company, Tulsa, Oklahoma, in charge of geophysical work.

DJEVAD EYOUB has returned to San Antonio, Texas, after a year spent in investigating the petroleum possibilities of the Republic of Turkey. Mr. Eyoub was employed by the Turkish government to make this investigation.

STANLEY C. HEROLD, consulting geologist and engineer, 1202 C. C. Chapman Building, 756 South Broadway, Los Angeles, California, has joined the staff of the *Oil Bulletin* as one of its contributing editors. Mr. Herold intends to make appraisals of leases and royalties, advise on oil investments, and carry on geological examinations with respect to oil and water supply. Through appointment by the Secretary of the Interior, Mr. Herold acts as engineering umpire at Kettleman Hills.

ROBERT S. CHRISTIE, petroleum engineer, Amerada Petroleum Corporation, at Hobbs, New Mexico, has an article in the November issue of *The Petroleum Engineer*, entitled "Hobbs Conditions Necessitate Elaborate System of Handling Mud."

PAUL D. TORREY, of Torrey, Fralich, and Simmons, geologists and petroleum engineers, Bradford, Pennsylvania, has an article on "Operation of Water Flood Properties Under Proration Schedules" in the November 12 issue of *National Petroleum News*.

VIRGIL R. D. KIRKHAM, of Lansing, Michigan, has a paper on "Old Erosion Surfaces in Southwestern Idaho," in *The Journal of Geology* for October-November.

W. E. WRATHER, 4300 Overhill Drive, Dallas, Texas, has been named president of the Dallas Art Institute.

DEAN E. WINCHESTER, consulting geologist, Denver, Colorado, is spending a large part of his time assembling data for a bulletin on the oil and gas resources of the state of New Mexico for the New Mexico State Bureau of Mines. The results will be published as a bulletin accompanied by maps and charts and will include not only complete data on the past developments and production, but a discussion of some of the future possibilities.

JOSEPH H. TURNER, formerly district geologist, and CHESTER D. WHORTON, formerly field geologist, of the Independent Oil and Gas Company at San Antonio, have opened a consulting office at 406 Milam Building, San Antonio, Texas.

L. L. FOLEY, of the Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma, presented a paper on "Mechanics of Folding and Jointing" before the Tulsa Geological Society on November 17, 1930.

Members of the Association are cordially invited to attend the forty-third annual meeting of the Geological Society of America, which will be held at Toronto, Canada, December 29-31, 1930, under the auspices of the University of Toronto. Ellis Thomson, honorable secretary of the Toronto committee, University of Toronto, will make room reservations in the dormitories.

CARROLL H. WEGEMANN, of New York, has returned from Monterrey, Mexico.

E. B. HOPKINS, of New York, LEON F. RUSS, of Dallas, and D. R. SEMMES, of San Antonio, were engaged in professional work in Mexico last month. Mr. Hopkins is residing in San Antonio, Texas, for the winter.

HOWARD F. NASH, who was formerly in the employ of the Imperio (The Empire Companies) of Mexico, was sent to Batavia, D. E. I., last July.

CHARLES MILTON has returned to the United States after working for the Cia. de Petroleo de Angola in Portuguese West Africa.

PAUL RUEDEMANN, of Tulsa, Oklahoma, was on a business trip to Monterrey, Mexico, last September.

WALT M. SMALL spent part of August and September in professional work in Fort Worth, Galveston, and Houston, Texas. In parts of October and November he was in Tampico, Victoria, and Monterrey, Mexico, from which he has returned through San Antonio, Houston, and Dallas. Mr. Small has recovered from the illness contracted last March while in Portuguese West Africa.

On October 7, 1930, in Volume XII, No. 30, of the *Diario Oficial* of the Mexican Federal Government, there was published a regulation of the petroleum code permitting unit operation of oil concessions.

The Huasteca Petroleum Company has moved its Monterrey geological force back to Tampico, Mexico.

BERNARD H. LASKY, geologist of Tulsa, Oklahoma, went to California in November.

C. BURCKHARDT, General Leon 60, Tacubaya, Mexico, D. F., is the author of "Etude synthétique sur le Mésozoique mexicain," published in the *mémoires de la Société Paleontologique Suisse*, Vols. 49-50, Basle, Switzerland.

RALPH H. CUMMINGS and WALTER R. BERGER have opened an office at 1001 Fort Worth National Bank Building, Fort Worth, Texas, and will engage in general consulting and appraisal work, specializing in oil and gas properties.

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Page 364, line 9: an asterisk should precede "Goodrich."

Page 678, fifth line from last, exclusive of footnotes: "Geologists" should be *Paleontologists*.

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Page 1228, line 16: "265°" should be *365°*.
Page 1379, line 5 in abstract: "southward" should be *northward*.
Page 1391, line 10 after table: "106,000,000 barrels" should be *1,060,000 barrels*.

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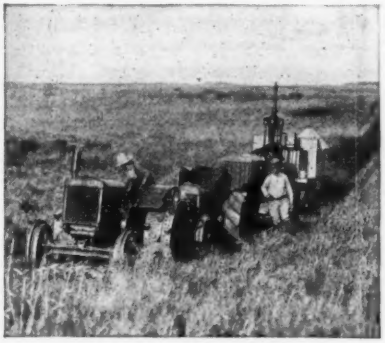

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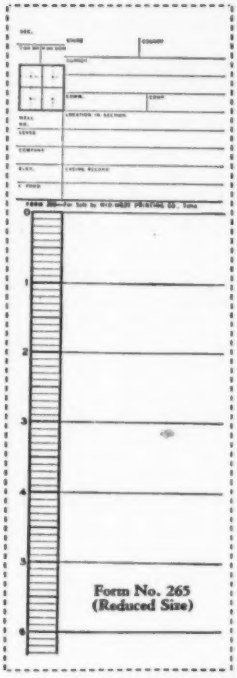

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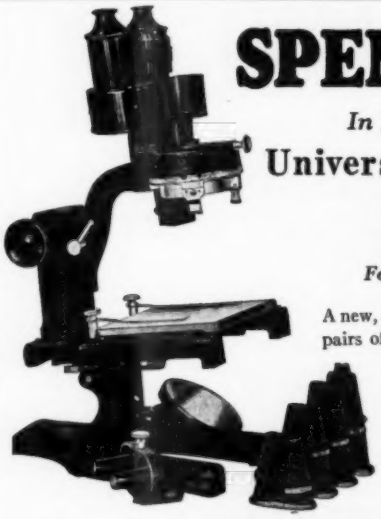

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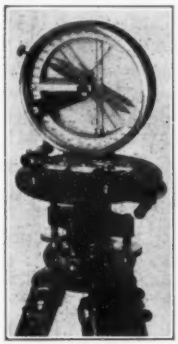

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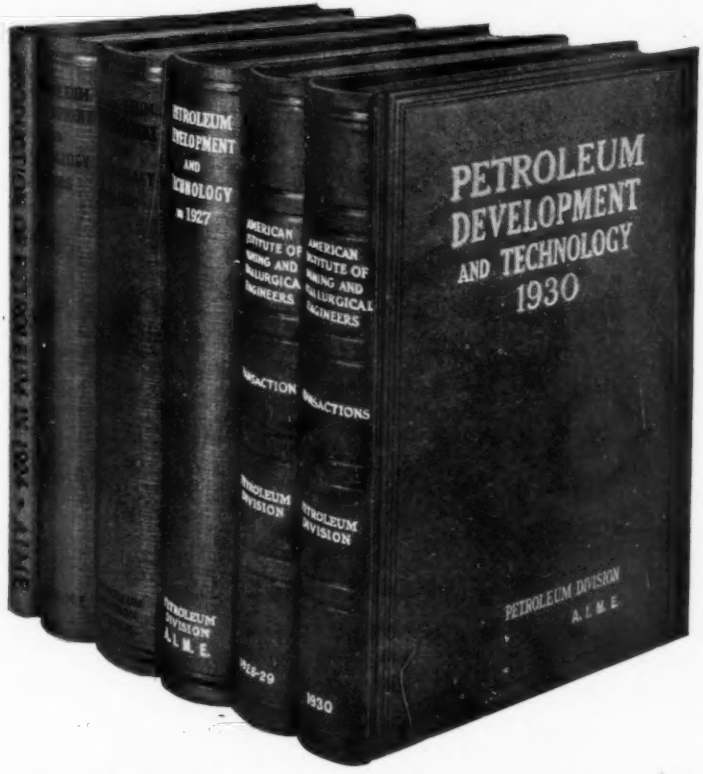

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